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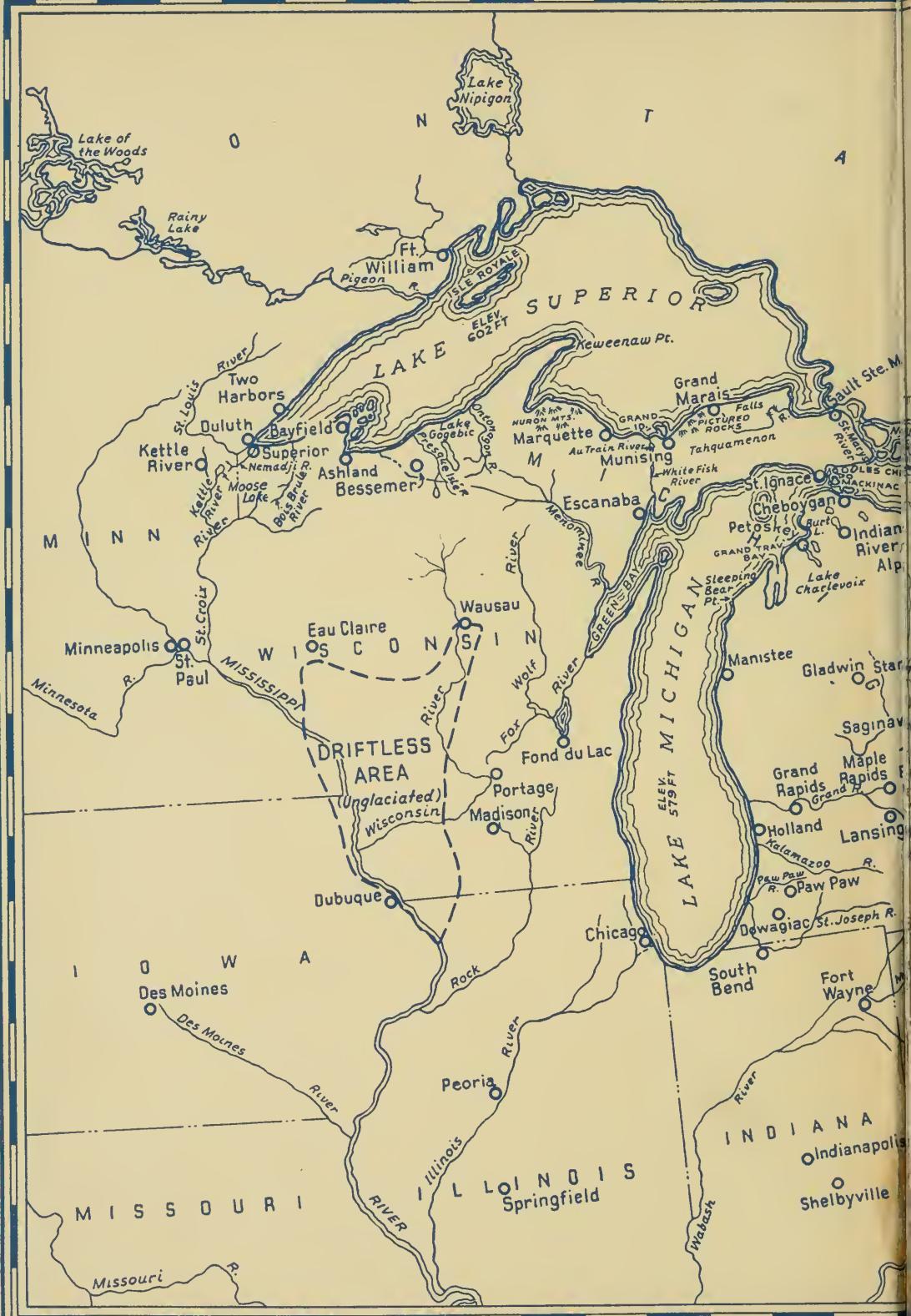
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NE-SAW-JE-WON



A TALE OF
THE WATERS THAT RUN DOWN
FROM LAKE SUPERIOR TO THE SEA

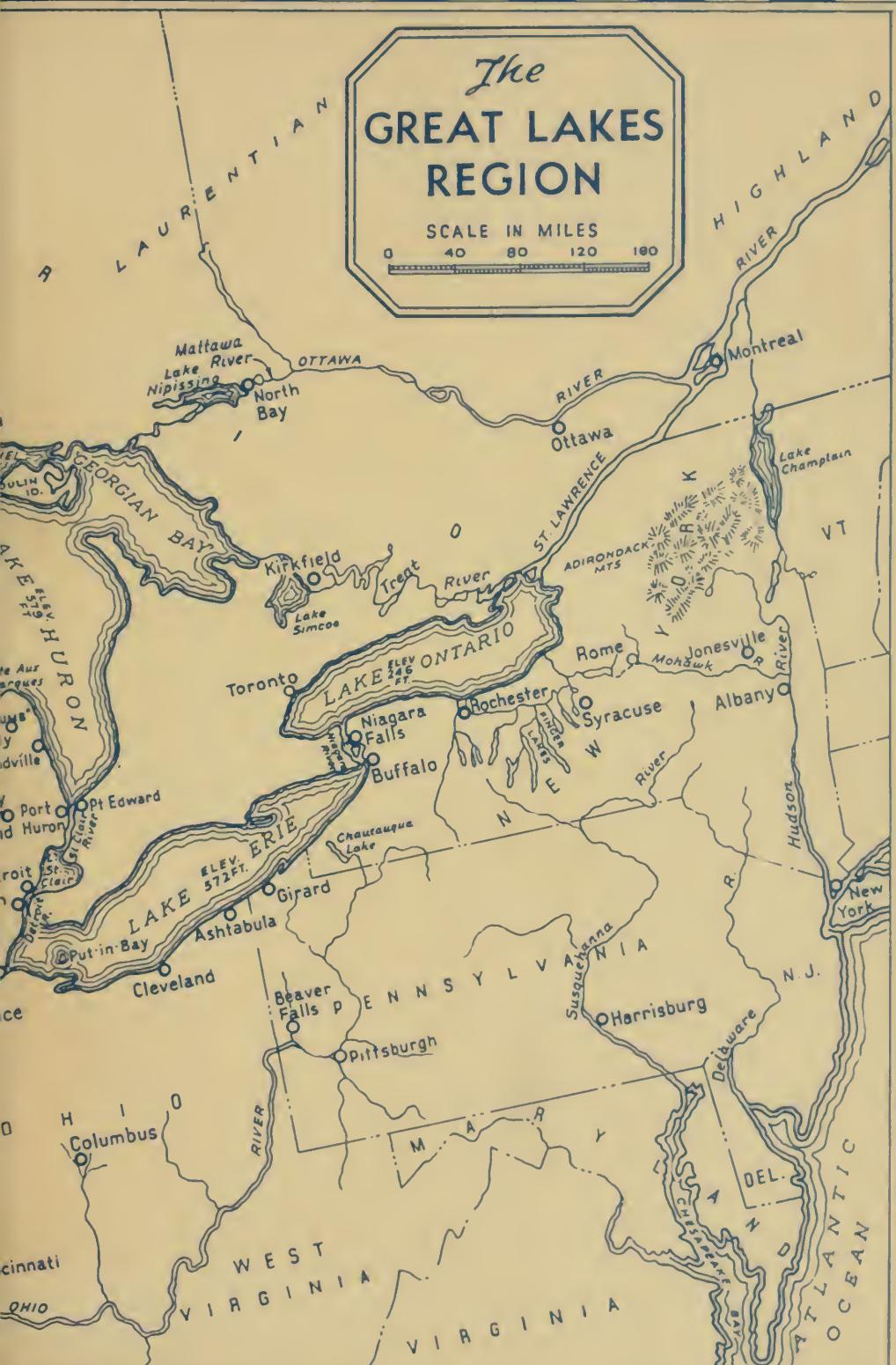
by
HELEN M. MARTIN



The
**GREAT LAKES
REGION**

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Cleveland, Ohio

“N E - S A W - J E - W O N”

as the Ottawas say

A Tale of
THE WATERS THAT RUN DOWN
FROM LAKE SUPERIOR TO THE SEA

by

HELEN M. MARTIN

*To Dr. Frank Leverett and to the Memory of
Mr. Frank B. Taylor:*

Through nearly half a century Dr. Leverett and Mr. Taylor explored and deciphered the records made by the continental glaciers during the Ice Age. From their studies was revealed the fascinating history of the Great Lakes. They travelled, mainly on foot, thousands of miles along the glacial moraines and over the beaches, shores and beds of the ancient lakes, measuring, recording and mapping as they went. They embodied their observations and conclusions in many scientific publications. Their work and their lives have been an inspiration to other geologists who have followed their footsteps and to many students who absorbed, in their lecture halls, the interesting story of glaciation. Much of this tale—NE-SAW-JE-WON, of "the waters that run down from Lake Superior to the sea"—is drawn from their classic volume, "The Pleistocene of Michigan and Indiana and the History of the Great Lakes," and from Dr. Leverett's "Moraines and Shore Lines of the Lake Superior Region"—publications of the United States Geological Survey.

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FOREWORD

THE Story of the Great Lakes, familiar to geologists the world over, is so romantic that it should be known to all who find pleasure in understanding natural environment and the manner of its development. The story should have a strong appeal to all who know and love the broad waters of the Great Lakes and the picturesque beauty of their shores.

Several years ago a group of business men, accustomed to a mid-summer trip together on a lake freighter, each day afloat gathered to discuss subjects of mutual interest. One of them, a geologist, contributed a series of informal talks on the Geology of the Great Lakes Region and the History of the Lakes, drawing illustrations from the rocks and shore features that could be observed from the ship. So much interest was aroused by these discussions that eventually it was planned to have the story written in brief, popular form, with the necessary maps and illustrations, so that it could be read at leisure and retained as a memento of such voyages.

Years passed without any action being taken on this idea, until in the fall of 1938, Miss Helen M. Martin, geologist, associated with the Michigan Geological Survey, was engaged to prepare the manuscript. As she is intimately familiar with the geology of the lakes region and is a former student of Dr. Frank Leverett (who, with the late Frank B. Taylor, is mainly responsible for what is known of the origin and development of the Great Lakes), Miss Martin is especially qualified for this undertaking. In the spring of 1939, her manuscript, sketch maps and photographs were turned over to Mr. M. D. Harbaugh, who has done the editorial work, prepared final drawings, and designed and directed the publication.

For this little volume, the reader is indebted to Pickands, Mather and Company, The M. A. Hanna Company, The Cleveland-Cliffs Iron Company, and Oglebay, Norton & Company. They join with others who have had a part in giving form to the idea that initiated this booklet, in hoping that NE-SAW-JE-WON will be found interesting and instructive.

M. D. Harbaugh

Hanna Building
Cleveland, Ohio
July, 1939

NE-SAW-JE-WON

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NE-SAW-JE-WON

SKETCH OF THE STORY

ABOUT a million years ago, when in far-off Java Pithecanthropus Erectus, the Ape-man, was fumbling his way to the man species, a river system occupied the Great Lakes region, flowing from the highlands of eastern Canada probably to the Gulf of Mexico. But about that time glaciers, which developed far north in the Hudson Bay region, started to move southward and eventually erased or buried much of the record of that river. Half a million years later the Peiping man, Sinanthropus, was buried in the limestone caves of China, and in North America the continental ice sheet reached as far south as Kansas. Then during a time of genial climates the ice front retreated, and perhaps the ice melted almost entirely from the region which is now the United States. Vegetation followed the northward movement of the ice front, and a rich soil was developed over the glaciated region of North America. In Europe the Heidelberg and Piltdown men made their appearance, but we have no evidence as yet that man had arrived on this continent. Then some 150,000 to 200,000 years ago, when the Neanderthal man was living before the ice front in Europe, the ice re-advanced in North America. It covered the Great Lakes region and moved as far south as southern Illinois near Cairo, to a point ten miles south of the Ohio River near Cincinnati, and to Beaver Falls in western Pennsylvania. North America became the most icebound of continents. In the centers of accumulation about the Hudson Bay region the ice is estimated to have been from three to six miles in thickness.

Thirty-five thousand years ago, when the Cro-Magnon—the first of modern men—were hunting the mastodon in southern Europe and drawing rude pictures of their kill on

the walls of their cave homes in southern France, the North American ice sheet again had melted back some hundreds of miles; in northwestern Ohio pools of water gathered along its front, and the Great Lakes had their beginning.

When the Folsum-Yuma men were hunting bison on our western plains, twenty thousand years ago, the glacier melted away from the ledge of limestone at Lewiston, New York, on the Niagara River, and Niagara Falls was born. Ten thousand years later, when our present civilization was dawning in the Near East, the ice had melted entirely from the Great Lakes basins; only a small lake in the Erie basin spilled over Niagara Falls, and the three upper lakes poured their waters in a wide torrent through the Ottawa River valley, in Canada, into the Atlantic Ocean which by then had entered and drowned the Gulf of St. Lawrence as far west as the vicinity of Ottawa, Ontario. Some three thousand years ago—perhaps about the time the camel caravans of King Solomon were bringing copper ores to the smelters of the great king at Exion-Geber and his argosies were sailing the Red Sea, when the glamorous Queen of Sheba brought gold and spices to the ruler of Judeah, when the people of Central and South America were building great pyramid temples to the Sun-God—a sluggish river crossing the flat lands now covered by Lake St. Clair was quickened by flooding waters, as the three upper great lakes deserted their eastern outlet through Ontario and poured their waters southward through the St. Clair and Detroit rivers, and the present Great Lakes system was established.

This is no fantastic tale of idle dreaming; it is a sketch of events in the Story of the Great Lakes—a romance of Nature's slow, gradual change of the face of the continent, an Autograph of Time which the lakes themselves in main part have written—the Story of "NE-SAW-JE-WON," as the Ottawas say, meaning The Waters That Run Down From Lake Superior To The Sea.

THE STORY OF THE GREAT LAKES is largely a story of the Ice Age in North America, a period geologically recent, which began only about a million years ago. But the events of the preceding eons of geologic time—hundreds of millions of years—when the forces of Nature were warring over the tasks of building, tearing down and rebuilding the rock formations of the continent, all played parts in preparing the stage for the drama of the ice invasion.

THE ROCK FORMATIONS AND PRE-GLACIAL HISTORY OF THE GREAT LAKES REGION

In the days when the Earth was young and turbulent, the Great Lakes region was the basin-shaped floor of the sea bordering a shield-shaped mass of igneous rock lying to the north—the initial North American continent. Several times in the eons that passed, as the Earth settled down and the continents became stable, the borders of this land were uplifted to mountain height, only to be worn down almost to sea level during long periods of quiescence. Finally a great convulsive, though slow, earth movement lifted to Alpine heights a mountain range extending from Minnesota and Wisconsin, in a northward-bearing arc, to the Laurentian Highland in Canada and the Adirondacks in New York. The several uplifts, whether slow or violent, changed the rocks so that the borders of the continent came to be a region of igneous and metamorphic rocks—granites, gneisses, schists, lavas, slates, and bedded rocks which were crumpled and folded. In the west these mountains have long since been worn away almost to their roots, leaving only rugged uplands in the highlands surrounding Lake Superior.

When earth forces brought uplifts of this vast area, they were accompanied by local downwarps or flutings of the sur-

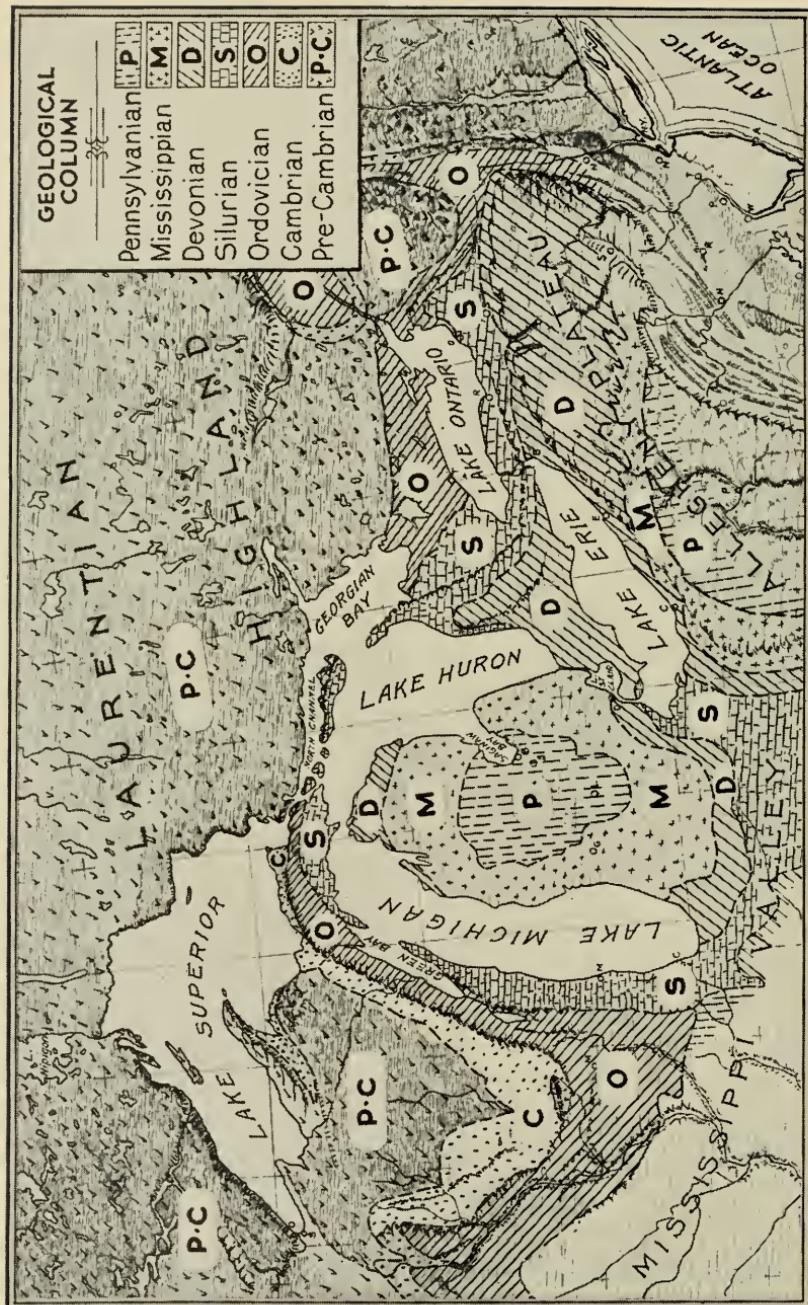


FIGURE 1.—GEOLOGICAL MAP OF THE GREAT LAKES REGION

Adapted, by permission, to a part of the *Physiographic Diagram of the U. S.*, by A. K. Lobeck, Columbia University.

face. One of these depressions, produced late in this early history, in time became the elongated curved basin of Lake Superior. Another much older depression, centering in the Southern Peninsula of Michigan and there more or less circular in shape, extended eastward in a rising scoop-like trough to east-central New York. This depression became the basin in which later invading seas deposited a great series of layered formations, one above another, made of the sediments weathered and eroded from the ancient rocks of the adjacent uplands. Slow earth movements caused sea after sea to enter and withdraw or be spilled from this basin, each sea being smaller than and within the boundaries of its predecessor, and each leaving layers of accumulated sedimentary material to be buried—in the central area of the basin—by the deposits of its successor. These sediments were compressed and hardened into rock—sandstones, limestones, shales, rock salt and gypsum. Coal beds, formed from the abundant vegetation which grew in the marshes associated with the later seas, were inter-bedded with the upper rock formations.

With the withdrawal of the last sea the land was elevated, and a long period of weathering and erosion followed. The highest portions of the bedded rocks around the rim of the scoop-like basin wore away first, bevelling the edges of the basinward-sloping rocks but not disturbing the lower portions in the interior of the depression. Thus developed a series of gigantic "rock bowls"—one within another—occupying the basin. They are like a great nest of mixing bowls with lips to the east. Some of the rock layers are hard and resistant to weathering, others are soft and easily eroded; hence in time the once-beveled edges of the resistant sandstones, limestones and dolomites came to have the general appearance of a series of parallel, concentric, stone "ramparts" with steep outward-facing exposures and gentle inner slopes toward the basin. These are separated by the depressions worn in the softer, less resistant layers—the shales, salt and gypsum beds. Where

these soft beds are deeply carved and gouged out along their exposures they may be likened to "moats" between the ramparts of harder rock.

Without going into detailed descriptions of each set of rock bowls, let us rather consider their relation to the development of the basins of the Great Lakes. As flowers, trees and people have distinctive family names, so names have developed to designate the rock formations. English geologists first studied the sedimentary rocks in England and Wales, and the names given the formations there have now been applied all over the world to rocks which have the same relative positions and are similar in character and in the life records or fossils contained in them. The lowest and oldest of the sedimentary rocks known to the early geologists were named Cambrian, from Cambria in Wales where they were first studied. For convenience, all the older igneous and metamorphic rocks are grouped as pre-Cambrian. Above the Cambrian, in parts of North America but not in Europe, is the Ozarkian, named from the Ozark Mountains; the next set of higher and younger rocks is the Ordovician, named from an ancient tribe of Wales; over the Ordovician rocks are the Silurian, also named from an ancient tribe of Britons that lived in Wales; then come the Devonian, commemorating Devon in England; and above these are the Carboniferous rocks—the Mississippian and the overlying Pennsylvanian. (Figure 1.)

Insofar as the Great Lakes are concerned, the important facts about the rocks are their arrangement and position and their different degrees of hardness. The pre-Cambrian rocks, which are hard and resistant to weathering, are downwarped to form the basin of Lake Superior. The Cambrian is a very resistant, coarse sandstone underlying the Ozarkian sandy dolomite, dolomitic sandstone, and dolomite. The thin edge of the Cambrian or Lake Superior sandstone, which once rested upon the pre-Cambrian rocks, has been weathered away until now its northern edge stands as the outer rampart of red,



Photo by Michigan Department of Conservation

PLATE 1.—“PICTURED ROCKS” RAMPART OF CAMBRIAN
SANDSTONE

SOUTH SHORE OF LAKE SUPERIOR; NIPISSING AND MODERN LAKES.

gray and white sandstone, rising majestically two hundred feet above Lake Superior, facing the moat of the Superior basin. It is the most battlemented of all the ramparts, and on it Nature has painted her “Pictured Rocks” and carved architectural designs that delight and awe the beholder. We can follow this Cambrian rampart from Sault Ste. Marie to the eastern half of the Keweenaw Peninsula,* and from east of Marquette we can trace it southward into south-central Wisconsin, where it swings westward around the old, igneous land-mass of central Wisconsin. Short streams entering Lake Superior from the south leap over the edges of the sandstone

*The sandstone in the basin of Keweenaw Bay, which forms the rampart along its shore and east nearly to Marquette, may be of pre-Cambrian age. (*Editor.*)



Photo by Michigan Department of Conservation

PLATE 2.—FALLS OF TAHQUAMENON RIVER

LARGEST FALLS WEST OF NIAGARA—300 FEET WIDE, FALLING OVER A
LEDGE OF CAMBRIAN SANDSTONE.

into Lake Superior or reach the lake in cascading beauty of misty falls over the fortressed cliffs. The tranquil 300-feet-wide Tahquamenon River falls in majestic grandeur over ledges of red-brown sandstone at the Upper Falls, rushes through a gorge it has cut in the rock to the ledges of the Lower Falls, and then winds again tranquilly on to the lake. Other streams have cut short gorges in the sandstone, but the positions of their falls near the lake are maintained and destruction of the falls is prevented by the layer of resistant Hermansville (Ozarkian) limestone, which is the rim of the next inner rock bowl.

Above and within the white, sandy Ozarkian dolomites and limestones were deposited the lime muds which became the hard, resistant limestones of the early Ordovician—the Black

River and Trenton limestones. The Menominee and Whitefish rivers cascade over the northern edges of these southward-sloping rocks to reach Green Bay and Lake Michigan. When the limestone-making sea became shallower, fine muds were deposited, and through countless ages these also hardened to rock—a soft shale. When exposed at the surface the shale did not resist weathering but gradually was worn away to form the moat behind the Cambrian-Ozarkian-early Ordovician sandstone and limestone rampart. Today we find parts of that moat occupied by Green Bay of Lake Michigan, by North Channel and Georgian Bay of Lake Huron, and by the Lake Ontario basin in the eastward extension of the Ordovician rocks.

Following the time when the muddy seas of the late Ordovician deposited muds that became the soft shales underlying the Green Bay-Georgian Bay-Ontario moat, came the Silurian time of genial climates when in the warm clear seas life was abundant. Shelled creatures of many kinds swam the seas or crawled upon their floors, and corals and bryozoans built great reefs. The shelled creatures and corals died, shells and reefs were broken and buried in lime mud, and through long ages the muds hardened to limestone filled with the petrified remains of a life long past. So hard and resistant to weathering is this rock that it formed the next great encircling rampart. This limestone is named Niagaran, because of its exposure along Niagara River—particularly at the brink of Niagara Falls. From western New York south of Lake Ontario, the Niagaran limestone rampart extends northwesterly across Ontario in a broad arc separating Georgian Bay from Lake Huron, rises to the surface as Manitoulin and Drummond islands, continues across the eastern half and forms the south shore of the Northern Peninsula of Michigan (excepting St. Ignace Peninsula), then circles southward between Green Bay and Lake Michigan along the Lake Michigan shore of Wisconsin to the southern end of Lake Michigan, where it forms the

sill holding the waters of the lake in the basin. Where the shales which underlie it are cut away, the Niagaran rampart stands in places like a cornice, rather than with the fortress-like character of the Cambrian sandstones; but it is sufficiently impregnable to have played a most important part in the development of the lakes. The close of Silurian time was marked by dry climates and by a shrinking sea from which life almost departed and which left enormously thick beds of salt and thinner beds of gypsum.

Then came a return of more genial climates, and a warm sea—the Devonian—entered the lake region and left thick sediments in the deep basin of the Michigan area. A part of the Devonian record is in the limestone which makes the rampart along the northern rim of the Southern Peninsula of Michigan from the Traverse Bay area to Alpena, which is submerged under Lake Huron, crosses Ontario and swings back again into southeastern Michigan, northern Ohio and Indiana, and which forms the western bowl in which the thick soft shales of the late Devonian and early Mississippian were deposited. These soft shales, together with the shales and salt beds of the late Silurian, in time were carved out to form the moat back of the Niagaran rampart, and in them the channels of great rivers were cut—rivers which carved valleys now filled by Lakes Michigan, Huron and Erie.

Above the thick shales of the lower Mississippian is a hard sandstone overlain by limestone and gypsum beds. Parts of the sandstone and limestone rims come to the surface near Holland, Michigan, and also along the shore of Lake Huron—around the “Thumb” of Michigan and along the opposite shore of Saginaw Bay. The southern rims of these Mississippian sandstone and limestone bowls are near the surface along an arc extending from the Thumb through south-central Michigan to Holland, and although inland, they played their parts in the lake history.

Within the Mississippian bowl in Michigan is the set of

Pennsylvanian sandstones, shales and coal beds. These had little to do with the story of the Great Lakes, except that a bit of their eastern rim was cut into to form the southwestern end of Saginaw Bay.

After Pennsylvanian time no seas entered the immediate area of the Great Lakes, and for many millions of years Nature was busy cutting, carving and wearing away the rocks laid down in the region. The soft shales and salt beds were eroded to form the wide moats, or trenches, between the more resistant formations which made the escarpments, evidences of the channels by which the seas had entered the region were obliterated, and a thick soil cover was developed. However, Nature was very busy building up the rest of the continent of North America—folding the Appalachians to mountain height, wearing them down to almost a plain, then lifting them again in a wide plateau which since has been carved to the Appalachian Mountains as we know them now. The Great Plains were built up, the Sierras and then the Rockies uplifted, and the mountains of the ancient pre-Cambrian area about Lake Superior were worn down. In the entire lake region we have no rock records of this time—known as the Mesozoic and Cenozoic eras, yet we know that with the general uplift of the continent this region was lifted much higher above sea level than it now stands.

The force that lowered the northern part of the continent and changed the ancient river valleys to lake basins started its work about a million years ago when a climatic change took place. The winters became not so much colder, but longer—so long that the snows of one winter were not melted by the summer sun before another winter set in. This time period we know as the Pleistocene, the age of the great continental glaciers which build the final rock record in the Great Lakes region. It ended when the ice had melted to the small remnants of the Greenland ice cap. Geological formations now in the making are known as Recent.



FIGURE 2.—GLACIAL MAP OF NORTH AMERICA
SHOWING THE MAXIMUM EXTENT OF THE ICE SHEETS AND THE SEVERAL
CENTERS OF ICE ACCUMULATION.

From U. S. Geological Survey.

THE GLACIAL PERIOD AND ITS RECORDS

During early Pleistocene time, in the highlands about Hudson Bay snow accumulated throughout hundreds of years and became packed to ice so thick that it pushed outward by

its own weight, just as a mass of clay or dough piled on a board spreads outward from its thick central mass. Once started to move, the mass of snow-ice became a glacier, which is estimated to have been from two to six miles thick and which reached a maximum extent of approximately 1600 miles from its center to the Ohio Valley. Four times during that million years the ice advanced over and retreated from the continent. Each advance had some effect upon the lake region, but it is only with the last advance—the so-called Wisconsin glaciation—that we are particularly interested. This last advance obliterated or buried much of the record of the earlier invasions, although it did not quite reach to the Ohio valley, as the preceding Illinoian invasion had done.

Once started, the ice moved slowly, relentlessly southward from the Hudson Bay area. Its freezing grip clutched the loosened rock ledges and plucked them away; it crushed and scooped up the surface debris, absorbing boulders, sand and clay into its mass, and slowly carried forward its load of rock materials to deposit them far from their source. It used pebbles, cobbles and boulders frozen in its base as great files, rasps and plough points to scratch and groove the surfaces of the bed rock over which it passed; or with fine rock and clay it scoured and polished these surfaces and rounded and polished the boulders and pebbles within its mass. By the scratches, grooves and polishings on rock ledges, we know in what directions the ice moved. At times this last great glacier, like the others before it, melted faster than it pushed forward, so that the southward movement was somewhat pulsating; but in the main, for thousands of years it moved steadily southward, carting along within its mass unmeasured quantities of rock debris which it had taken from the lands to the north. When it reached the area of the Great Lakes, tongues of ice entered the river valleys in the ancient rocky moats and there became thicker and moved more rapidly. These river valleys were in the soft shales, hence the ice gouged and furrowed them; it



FIGURE 3.—GLACIAL MAP OF THE GREAT LAKES REGION
SHOWING THE DIRECTIONS OF MOVEMENT OF THE SEVERAL GLACIAL LOBES
AND THE POSITIONS OF THE ICE BORDER AT SUCCESSIVE STAGES IN THE
RETREAT.

From Frank Leverett and F. B. Taylor.

deepened and widened, but did not carve them to the U-shaped valleys which distinguish the action of glaciers in high mountains. These tongues or lobes of ice in the valleys that now are the basins of the Great Lakes acted almost as inde-

pendent glaciers, the ice advancing outward from their own axes or centers. Thus the ice in the Lake Michigan basin moved not only southward with the general movement of the glacier but also radially from the central axis, southwestward and southeastward, toward the edges of the basin. The ice lobes in other basins had similar movements, which are revealed in the rather complicated directions of the scratches, also by curious features carved in the bedrock and by underlying deposits of earlier glaciations.

Once past the old river valleys the ice fronts again united, and the glacier—shaped somewhat like a huge cauliflower with its stem to the north—moved southward almost to the Ohio River. Its extent is marked by the line of hills, known as terminal moraine, extending irregularly eastward from Shelbyville, Illinois, to southern Ohio, thence into northwestern Pennsylvania, and from there southeastward to and across Long Island. The advance was stopped by a slow climatic change which caused the ice to begin a lingering, halting retreat, marked by occasional readvances of the ice front, but nevertheless a continuous withdrawal northward. When the retreating ice front reached the ancient river valleys the glacier once again assumed the tongue or lobate character—thicker in the valleys and thinner on the uplands—each lobe again with the characteristics of an essentially independent glacier.

The records of the retreat are similar to the records of retreat of living glaciers, easily studied in the Alps and in the high Sierras, which furnish the clues to the work of the continental ice sheet. The records are mainly in long lines of hummocky hills—moraines—of rock debris which the ice deposited as it melted. When the rate of forward push of the ice was equalled by the rate of melting at its border, the ice front remained stationary for many—probably hundreds—of years, and the rock waste brought from the north settled out of the melting ice at its edges, accumulating there like

debris on a city dump. Obviously, this material is a collection of all sorts of unrelated odds and ends of rock material from the varied surfaces over which the ice had passed. The melt water sorted out some of the debris and carried it away from the ice front, building up deposits called outwash plains or aprons, the coarser gravel being left near the moraines and the finer gravel, sand and silt being carried farther away. The moraines may be likened to entrenchments thrown up for protection by the retreating ice in the warfare between heat and cold. They mark the lines of halt and reinforcement, followed by giving-way and further retreat, as the warming climate slowly forced the glaciers from the continent. A rapid retreat, when the forces of heat were great and when melting was more powerful than the forward push, caused the rock debris to be deposited in gently undulating plains of commingled sand, clay and stones called till. These deposits, known as ground moraine or till plains, are similar on a large scale to the dusty, clayey deposit left on the surface after a persistent winter snowbank has melted. Formation of the till plain was stopped at each halt, as the ice built another backstep moraine. Long roughly parallel lines of morainal hills, stretching from Pennsylvania to Illinois, mark the retreat of the Wisconsin glaciation in the Ohio valley region. But when the ice had retreated to the Great Lakes area the valleys of the ancient river systems again determined the shape of its front; again the ice assumed lobate form, the lobes acting as independent glaciers in the Lake Michigan, the Huron-Erie and the Superior basins. The moraines which mark the halts of these glacial lobes are festooned about the basins in lines of hummocky hills which roughly parallel the borders of the present lakes. In time, as melting progressed, the lobes came to be more completely separated, so that distinct glaciers occupied the basins of Lake Michigan, Green Bay, Lake Erie, Lake Huron, Saginaw Bay, and finally the Ontario basin. In the Lake Superior region the ice probably divided into lobes

on either side of Keweenaw Peninsula. In places the moraines of adjacent lobes were pushed together, making a jumble of high hills such as the scenic Irish Hills of southeastern Michigan and the high hills of the northern part of the Southern Peninsula. These morainic hills, with their beautiful lakes of ponded waters and with clear streams rushing down their slopes, give to the glaciated region its varied and picturesque beauty. Other parts of the country have hills carved from the bed rock of the region, but the glaciated district, particularly in Michigan, has also hills built by a plastering of rock waste scraped off Canada, transported and dumped by the ice. The ice in the Saginaw Bay lobe melted faster than the ice of the Michigan and Huron-Erie lobes, because it was thin over the rim of the Marshall (Mississippian) sandstone—one of our old “rock bowls.” Its retreat was rapid and marked by brief halts, with the result that the moraines of that lobe are grouped in a necklace arrangement of pendant festoons about the bay—narrow belts of low rolling hills with broad flat valleys (outwash plains) between, in contrast to the high sharply-hilled moraines of the other glacial lobes. In other states of the glaciated area and in the Northern Peninsula of Michigan much of the bed-rock is exposed at the surface or the drift is thin, but in the Southern Peninsula the burial cover of glacial drift is so thick that bed-rock appears at the surface in but few places. Hence secrets of mineral wealth in the underlying rocks have been preserved until mechanical ingenuity made it possible to drill through the thick cover of drift.

High conical gravelly hills mark the sites of water falls where streams flowing in channels or tunnels high in the ice fell over its edge and piled their rock debris in dumps at the foot of the falls. Such hills, known as kames, standing alone or in groups of several on the till plain or in the terminal moraine, may be easily recognized by their form and by their water-sorted contents where these are exposed in excavations.

In the early-inhabited parts of the glaciated district they were used for burial places, as generally the soil cover was thin and their gravel content provided good drainage. In many places they furnish gravel and sand for road building and other construction. Long narrow hills that look like abandoned railway embankments mark the sites of walled or tunnelled channels of streams which flowed upon, within, or under the ice. These stream channels became choked with rock debris, and when the ice melted the water-sorted material settled to the land surface, its sides assuming characteristic steep angles of repose. These sinuous hogback ridges, known as eskers, may be from a few feet to more than a hundred feet high and from a fraction of a mile to many miles long. They are on the till plains and in the moraines.

Other strange products of glacial building are drumlins, curious hills shaped like inverted canoes, found on the till plains, aligned in the direction of the ice movement. Some drumlins, such as those on the limestone Cheneaux Islands, and the lenticular hills in the drumlin area of Grand Traverse, Michigan (found on excavation to have cores of shale covered with a plastering of pebble-set clay), evidently were "shaped into drumlinoid form by the ice passing over them"; some are sculptured till; and others are a special form of ground moraine—mounds of glacial till with elliptical bases. Drumlins may be from fifty to three hundred feet high and from one-fourth mile to one and one-half miles long; many of them are steepest on the end facing the direction from which the ice came. The exact manner of origin of these remarkable hills is a matter of much speculation. They are usually arranged in fan-shaped groups; and it is believed that in some way they were carved from old till by readvance of local ice lobes, or were accretions of till beneath the ice along margins of broad lobes—perhaps in long crevasses, or are hills carved in the bed-rock by the advancing glacier and coated over with stony clay left by melting ice. Excellent examples of drumlins may

be seen near the southern end of Green Bay, in Wisconsin; in Dickinson, Marquette, Delta and Menominee counties, the Les Cheneaux Island area, and in the Grand Traverse region, in Michigan; as well as in western and central New York.

All this plaster of rock waste quite foreign to the formations on which it lies—these moraines, kames, eskers, drumlins, outwash plains, till plains, mixed accumulations of all sorts, sizes and shapes of rock fragments—limestone, sandstone, jasper, granite, gneiss, chunks of copper, iron ore, rare flakes of gold, even a few diamonds, beds of clay, sand, gravel—spread over the glaciated region, is collectively known as drift, because early geologists believed it to have been spread by drifting currents and icebergs in an ancient sea. Its thickness varies widely; in some places it is very thin or entirely lacking and in others it is from 800 to 1,200 feet thick.

A large area in southwestern Wisconsin was never covered by the ice. Not because it was too high, but for some other reason, the ice deployed around it, leaving the famous Driftless Area in which the beautiful and interesting Dells of the Wisconsin River have been cut by that stream in the red-brown Cambrian sandstones. A small peak of rock standing like an island above a glacier is known by the Eskimo name "nunatak." Around such a nunatak in Ontario the ice deployed in its forward march and formed the Huron and Erie lobes, and in the retreat the nunatak separated these lobes. Highlands in the Northern Peninsula once covered by the ice became nunataks for a time during the retreat.

As the glacier retreated northward, the melt water from the ice escaped in broad channels leading southward to the Ohio River and thence to the Mississippi. These channels, now the wide flat valleys of too-small rivers, furnished the routes for man-made canals in the heyday of canal building in Ohio. The great volume of glacial water reached the Ohio and vastly increased the size and activity of that river. Advance of the ice had pushed the river southward in the vicinity

of Cincinnati, but with removal of the ice barrier the river returned to its former course.

THE RECORDS MADE BY RIVERS AND LAKES

Nature today continues to make the same sort of records she has always made on the face of the earth. As the work of living glaciers supplies the key to knowledge of the ancient ice invasions, so does the work of modern streams and lakes furnish the key to the records made by rivers and lakes of the past. Each river and lake writes its own life-story. Starting as small rills or brooks, rivers increase in size as they acquire tributaries. At the same time they use tools found in their paths or supplied by tributaries—cobbles, pebbles, gravels, and even huge boulders in flood times—to cut and carve their channels deeper. Having deepened their channels to the limit of their power, they wear away their banks. The net result is the production of a valley, narrow near the source of the stream and widening into a broad flaring "V" toward the outlet. The cross-section of the valley is also V-shaped, being a sharp V near the headwaters and almost flat near the mouth. Tributary streams enter with their currents directed downstream, so that in time the river system has the familiar "tree," or dendritic, pattern. The streams increase in length by headward cutting (even when the source is in a lake, the lake is drained eventually) and by building deltas at the mouth and then cutting across them. As the river grows old, it will have drained the lakes in its course and built a wide flat on which it swings lazily and muddily from bank to bank, like the Mississippi. By contrast, in the areas which have been glaciated the drainage is poor and haphazard, for pre-glacial stream courses have been more or less filled with drift, the streams diverted, and waters ponded to form lakes and swamps. Tributaries may enter the main stream at any angle, valleys may be wider near the headwaters than near the mouth, small streams may occupy much-too-

wide valleys; or valleys which have all the appearance of river valleys may have no streams in them at all. In places beds of rounded gravel are left to mark the channels of departed streams; in other places rocky ledges show that they have been scoured by tools carried by rushing river waters. In a word, major streams in a glaciated region do not conform to any pattern; their courses are determined by the manner of deposition of the drift-cover rather than primarily by the slope of the land and the character of the bed-rock surface. Actually, many of the streams once flowed in directions opposite to the courses they now take, as, for example, Maumee River which now enters Lake Erie at Toledo: its drainage pattern is more like a double anchor than like a tree; its valley widens toward the headwaters which once flowed southwestward down the channel of the Wabash. A dry river channel now separates the Wabash and the Maumee near Fort Wayne, Indiana—a channel which has its place in the history of the Great Lakes, as well as in the history of the migrating Indians who used it as a trail and of the white men who there built a fort to guard the way to the west. The life story of most of the streams entering the Great Lakes is as varied as is the tale of the lakes.

Present-day lakes are making shore lines, beaches, strands and ridges; waves and currents wash sediments onto and along their shores; deltas are being built at the mouths of streams, or the mouths are being filled by wave and current action which curves the lake beaches into them; sands along the shores are rounded and etched to grains of distinctive character and are sorted and piled by the wind into heaps called dunes; pebbles shifted along the shores by currents and waves become flattened, showing their beach origin in contrast to the rounded pebbles shaped by rolling along in streams. (Such flattened pebbles on a beach are known as shingle.) The



Photo by Michigan Department of Conservation

PLATE 3.—BEACH ON MACKINAC ISLAND

LOOKING SOUTH FROM BRITISH LANDING. SHOWS CHARACTERISTICS OF A MODERN BEACH. STEP NOTCHES IN BACKGROUND ARE SHORES OF THE NIPISSING AND ALGONQUIN LAKES.

shore lines of lakes are being straightened to smooth curves, as waves and currents build bars, hooks and spits across the coastal indentations, making lagoons which in time become swamps and then flat muck-lands. Sand and gravel are left along the lake beaches, but the finer sediments are carried farther from shore, and the very finest muds are deposited in deep water. The manner of settling of these most-finely-ground muds supplies an interesting geological clock by which to actually measure in years the rate of accumulation of these sediments; and from their thickness can be derived an approximate age for the lake in which they were deposited. In the summer time when sediments are being washed into the lake, the coarser of the fine muds settle to the bottom rather

rapidly and build a layer of light-colored sediments. Then in the winter time when ice covers the lake or the land is so frozen that little or no sediment is washed from it, the very fine particles of silt and minute organic matter, which remained in suspension in the water all summer, gradually settle to the bottom in the cold quiet water and build a thinner layer of dark-colored sediments on top of the thicker summer layer. Such seasonal layers of alternating fine dark-colored and coarser light-colored clays are known as varves. It is evident that if a section cut through layers of varved clays to the original bed of a lake can be examined, the number of seasons the lake lived can be determined, just as the age of a tree is determined by the seasonal rings of wood that it acquires. If a lake exists long enough all depressions of its bottom will be filled to a common flat surface. At times the level of a lake may be raised, its area become larger, and its storm waves more powerful. The waves bite into the beaches, notching them on the lakeward side, cut into high lands along its shores, and make water-worn cliffs. If the higher stage exists long enough the lake may completely destroy the shore forms made at a lower level. If the borders of the lake are resistant rocky cliffs, the waves cut grottos and sea caves in them and pound the loosened debris on the shore into a narrow rocky beach. Outlets of lakes also have their distinctive characteristics. The lake beaches curve into the outlet and disappear in the channel, as the outlet assumes the character of a river and slopes away from the beach lines; thus old abandoned outlets can be identified.

If the lake dries up or is drained away all these records—beaches, strands, dunes, shore cliffs, sea caves, grottos, varved clays, flat lake-beds of sand and clay—are left high and dry, showing where the lake once was and revealing its history. The strength of these features indicates the length of time the lake endured. Obviously a short-lived lake would make weak, ill-defined shore features, whereas a long-lived lake

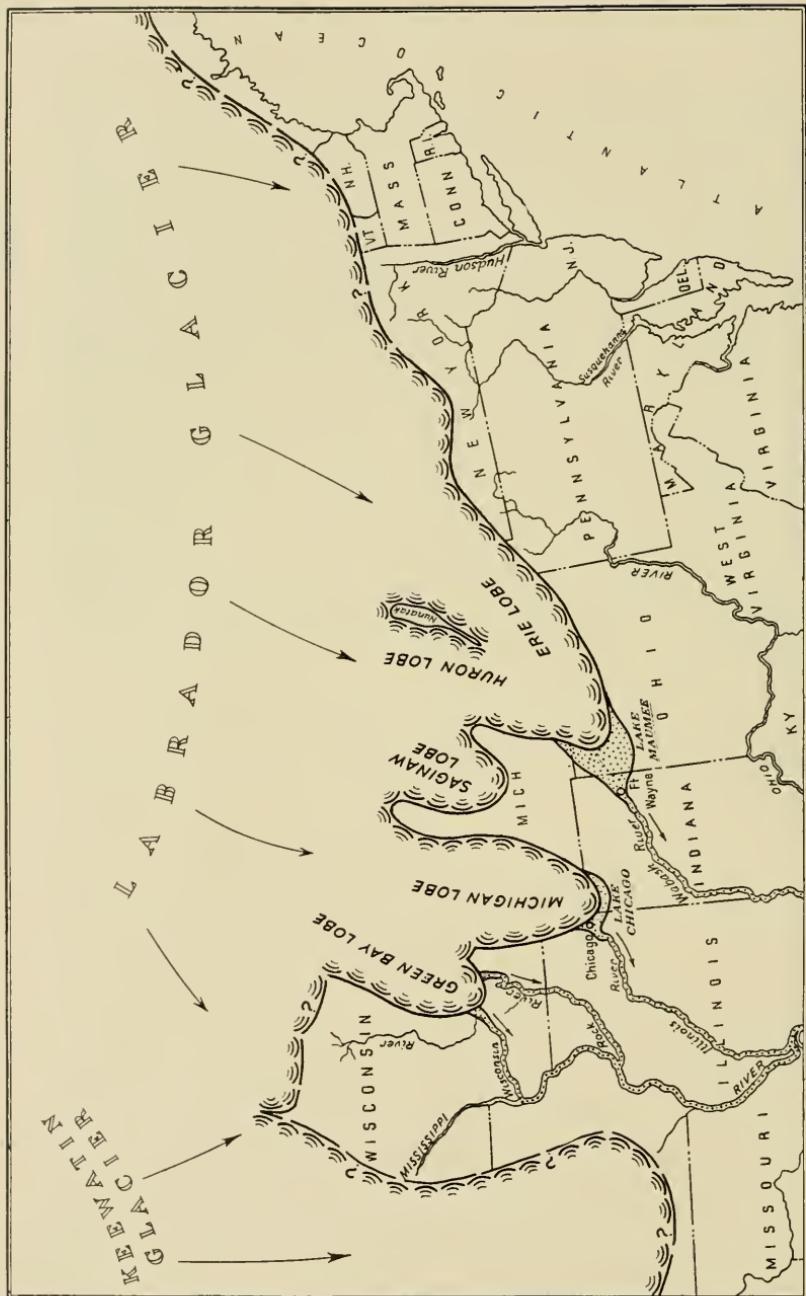


FIGURE 4.—FIRST OF THE GLACIAL LAKES—MAUMEE AND CHICAGO
EARLY LAKE MAUMEE, WITH OUTLET TO THE WABASH RIVER; INITIAL STAGE OF LAKE CHICAGO, WITH OUTLET TO THE
DEPLAINES AND ILLINOIS RIVERS.
After Leverett and Taylor.

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would cut and build strong and pronounced beaches, shore cliffs and terraces. It is possible that many lakes once existed of which we shall never have knowledge, for they left records so weak and faint as to be now illegible. At any given level of a lake the features of its shores and beaches must have been horizontal and all related to that elevation. If the lake becomes smaller and remains long enough at a lower level, new shore features will be made at that elevation; if it becomes larger the rising waters wash over the older shore lines but do not always destroy them. In fact, if the waters rise rapidly and the lake becomes deep, old shore features of a lower level may be well preserved; and if the new higher lake persists long enough, these features may be buried by its varved clays. Changes of lake level make all sorts of complications in the records, but because shores are horizontal when made, most of the records can be deciphered.

It is from such records of glaciers, rivers and lakes, some simple, others complicated, that we have been able to read and learn of the development of the Great Lakes.

LAKE MAUMEE—THE FIRST OF THE GLACIAL LAKES

When the ice had melted so far north that its front stood north of the drainage divide and the land sloped toward the ice, streams of melt water could no longer flow freely southward, hence the water collected in front of the ice in long narrow pools back of the bordering moraine. From the records such as those described, we know that the earliest glacial pools which formed along the edge of the ice lobe in the Erie basin were in northwestern Ohio. When the ice had melted far enough, several pools united to form a narrow crescent-shaped lake around the front of the Erie ice lobe. Thus was born the first of the great lakes—the ancestor of Lake Erie. Faint beaches were made by these early pools of melt-water, but the waters rose steadily and finally formed a strong beach at the highest level the lake reached, about 230 feet above the

present level of Lake Erie. At this stage the over-flow waters escaped over a "col" (low place between hills) in the impounding moraine and flowed from the lake-basin southwestward, past the site of Fort Wayne, to the Wabash River which had been one of the escape channels for the melt-water before the lake was formed. Thus the first outlet of the Great Lakes was via the Wabash and Ohio rivers to the Mississippi and the Gulf of Mexico. The Maumee River now flows into Lake Erie over the bed of this ancient lake, hence its name—Lake Maumee. (Figure 4.)

EARLY LAKE CHICAGO; LAKE JEAN NICOLET

Shortly after the formation of the first Lake Maumee, another long narrow lake began forming at the foot of the ice lobe in the Lake Michigan basin, between the retreating ice and the morainic barrier. This was the beginning of glacial Lake Chicago, the ancestor of Lake Michigan. Its outlet was through the lower channel of the present Des Plaines River, into the Illinois, and thence to the Mississippi and the Gulf of Mexico. Probably only a little later two small lakes formed at the southern end of the ice lobe in the Green Bay basin. The outlet of one of these was southward to Rock River and of the other southwestward to Wisconsin River, thence to the Mississippi and the Gulf. These lakes later united, forming glacial Lake Jean Nicolet which is of interest but of relative unimportance. It did not last long enough to make strong shores as an independent lake, for it soon merged with Lake Chicago, when the retreating ice opened passage to that lake.

Very much later a similar crescent-shaped lake was formed around the western end of the Superior ice lobe. It was known as glacial Lake Duluth, the ancestor of Lake Superior, and discharged southward through St. Croix River to the Mississippi.

From these four small crescent-shaped glacial lakes, ini-

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tially all outside the basins of the present lakes and all discharging southward to the Mississippi and the Gulf of Mexico, grew a series of lakes "which for size and complicated history is not known in any other part of the world." The total area which at some time has been covered by waters of these glacial lakes is considerably greater than the area of the present Great Lakes (now about 95,000 square miles), although the entire area submerged was not covered at any one time. Only one glacial lake was larger—Lake Agassiz, of which Lake Winnipeg is a remnant. Although it once covered 110,000 square miles, its history is very simple. It also was formed in front of an ice barrier during the retreat of the last glacier—the Keewatin ice sheet which late in the retreat of Wisconsin glaciation had pushed southward from a center west of Hudson Bay and had reached south as far as Des Moines, Iowa, over-riding the deposits of its earlier neighbor—the Patrician lobe of the Labrador ice. (Figure 2.) The Keewatin glacier persisted for some time after the formation of the incipient Great Lakes, thus Lake Agassiz came into existence long after the Great Lakes were well established. Its outlet was to the Mississippi before establishment of the present drainage. The bed of Lake Agassiz now makes the wheat lands of the northwest, in Minnesota, North Dakota, Manitoba and Saskatchewan.

The accompanying maps show the manner of development and the changes in the lakes more graphically than words can describe. Figure 1 shows the distribution of the rock formations which determined the location of the lake basins. Figure 2 shows the areal extent of and the centers of accumulation of the ice sheets which covered the northern part of North America during Pleistocene time. Figure 3 shows the directions of movement of the ice in the glacial lobes which occupied the several lake basins and the positions of the ice border at successive stages in the retreat. The other maps, in order, show the various strand lines and outlet streams of the

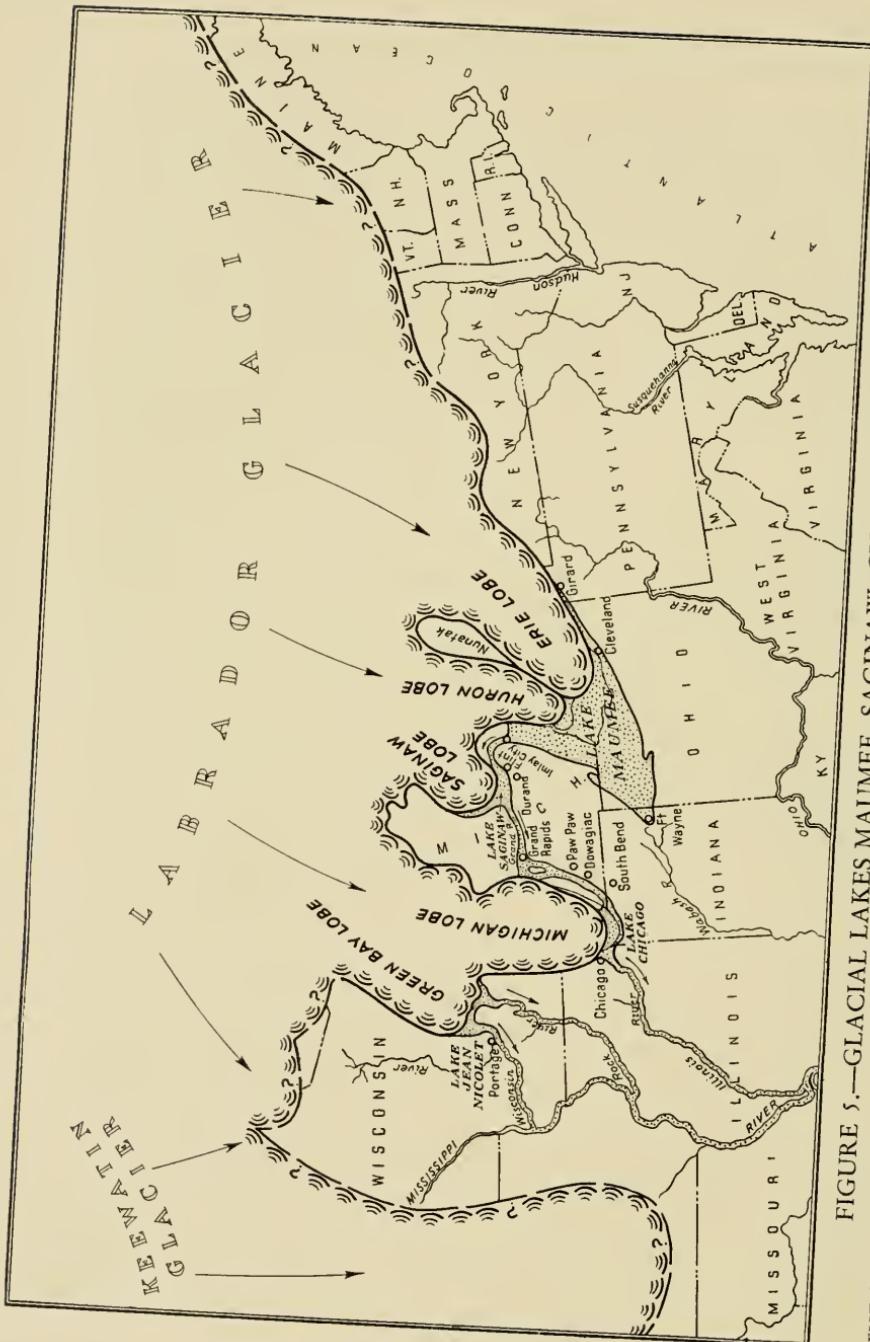


FIGURE 5.—GLACIAL LAKES MAUMEE, SAGINAW, CHICAGO AND JEAN NICOLET
 THE IMLAY OUTLET OF MAUMEE; GRAND RIVER OUTLET OF SAGINAW; ILLINOIS RIVER OUTLET OF CHICAGO; ROCK AND
 WISCONSIN RIVER OUTLETS OF JEAN NICOLET.
 After Leverett and Taylor.

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lakes, and also the probable positions of the ice front as marked by the terminal moraines made by the several lobes.

Glacial Lake Maumee (Figure 4) was curiously shaped, with long narrow arms extending around the edge of the Erie ice lobe and a funnel-like outlet southwestward to the Wabash River. Along the bordering moraine are the lake beaches, sloping eastward into the flat bottom of the old lake. The ice front of that time is marked by the line of hills known as the Defiance moraine (named from Defiance, Ohio), which swings around the position marking the edge of the Erie lobe from Ohio into Michigan. Where the lake bordered the ice the moraine was deposited in the waters of the lake.

THE SECOND STAGE OF LAKE MAUMEE

When the ice retreated from the Defiance moraine, it opened a northern outlet near Imlay City, Michigan, thirty-five feet lower than the Fort Wayne outlet. The waters of Lake Maumee then abandoned the Fort Wayne outlet and flowed in an arc across the Thumb of Michigan, past Flint and Durand, along the edge of the Saginaw ice lobe and into Grand River. (Figure 5.) Before that time Grand River probably had been only a trickling stream in a crease in the moraine. The change in outlet started the second and lowest stage of Lake Maumee, which lasted long enough for the lake to build typical beaches and shore formations, as it had done at the higher level. But from this time on the story of the lakes becomes very complex. Retreats of the ice front opened lower outlets and changed the direction of drainage discharge from the lakes; re-advances of the ice raised the level of the waters, closed older outlets and opened new ones. Almost every oscillation of the ice front was of a duration long enough for the lakes to produce their characteristic records. By patient search many of the old strand lines have been located, even though rising waters destroyed much of the

evidence during the glacial time, and wind, weather and man have obliterated much of the record since.

THE THIRD STAGE OF LAKE MAUMEE

From this second or lowest stage of Lake Maumee, the lake level was raised about twenty-five feet—almost to the level of the Fort Wayne outlet—by a re-advance of the

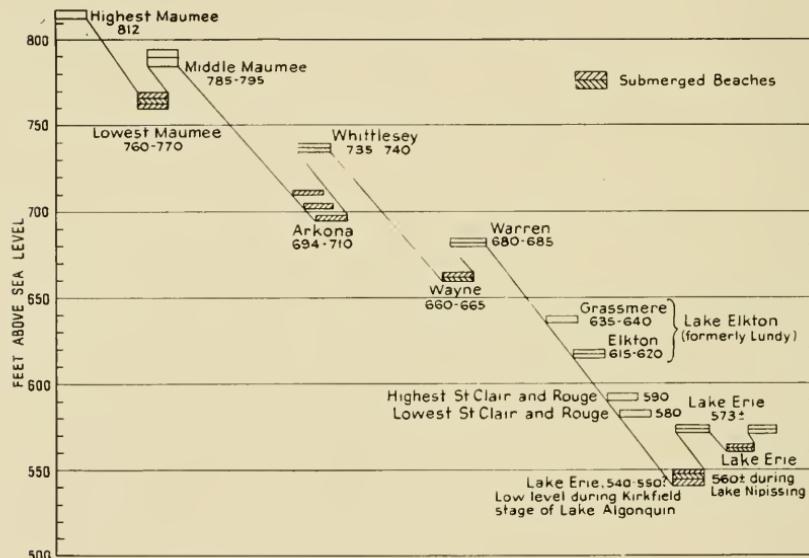


FIGURE 6.—DIAGRAM SHOWING WATER LEVELS OF THE VARIOUS STAGES OF LAKES IN THE ERIE BASIN

FROM THE FIRST LAKE MAUMEE TO THE PRESENT LAKE ERIE. (OLDEST AT LEFT. BEACHES SUBMERGED BY LATER EXPANSION OF THE PONDED WATERS INDICATED BY CROSS-HATCHED PATTERN.)

After Leverett and Taylor.

glacier, which moved westward up the slope of the highlands of the Thumb. The ice front finally rested along the east side of the Imlay outlet channel and there built a moraine which

crowded the channel westward. In this stage the lake reached its greatest extent. (Figure 5.) Curiously, it was lower than the first Lake Maumee but higher than the second, and stretched from Fort Wayne, Indiana, northward to Imlay City, Michigan, and eastward to Girard, Pennsylvania. The outlet continued through Grand River to the small Lake Chicago in the Michigan basin, and thence to the Mississippi. The ice front extended from the vicinity of Detroit across the basin of Lake Erie, at a distance of forty or fifty miles east of Toledo, so that along the ice the lake was 150 to 200 feet deep. As the ice formed the eastern and northern shores, the lake made no beach lines in Ontario.

Figure 6 shows diagrammatically the stages of Lake Maumee and of the later lakes which occupied the Erie basin in its step-like descent to its present level. From the highest to the lowest is over 270 feet.

LAKE SAGINAW

During the final stages of Lake Maumee the ice in the Saginaw Bay depression had retreated far enough so that a small shallow crescent-shaped lake was formed along its margin. This lake, known as Saginaw (Figure 5), became larger when it received the overflow drainage from the Imlay outlet river, and the waters of Lake Maumee and Lake Saginaw flowed past the site of Maple Rapids into Grand River, thence to Lake Chicago through a series of small lakes back of the lake-border moraine near Paw Paw and Dowagiac, Michigan. Lake Chicago also slowly expanded as the ice in the Lake Michigan lobe melted northward. At first the channel of Grand River was narrow, but gradually, as the flow from the lakes entered and scoured it, this became one of the mightiest streams of the North American continent—a mile to one and one-fourth miles wide and, near Grand Rapids, a hundred and twenty feet deep.

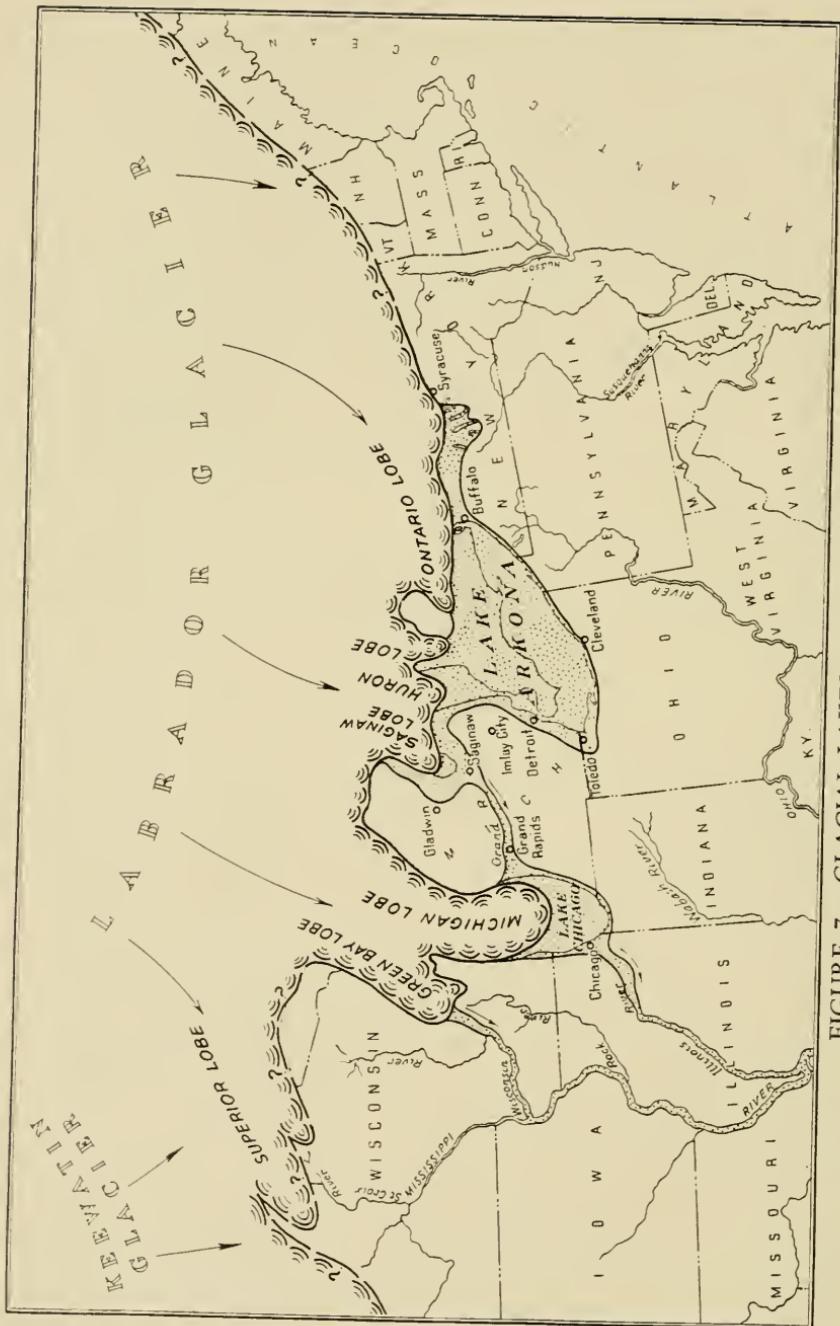


FIGURE 7.—GLACIAL LAKES ARKONA AND CHICAGO
GRAND RIVER OUTLET OF ARKONA; ILLINOIS RIVER OUTLET OF CHICAGO

After Leverett and Taylor.

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LAKE CHICAGO

As Lake Maumee increased in size Lake Chicago also increased and was building its highest beach, the Glenwood, a few miles south of Chicago. Lake Chicago never had the varied history of the other lakes. Its several beaches are parallel to the present beach and are so near Lake Michigan that in places they actually have been undercut and destroyed by the present lake. The outlet was through Des Plaines River to the Illinois and the Mississippi—the “Chicago Outlet,” now utilized by the Chicago Ship and Drainage Canal.

LAKE ARKONA

The next important step in the development of the lakes in the Erie basin was the rather sudden withdrawal of the ice from the Thumb region of Michigan. All the lake waters to the eastward fell to the level of Lake Saginaw, which had expanded northeastward in a broad strait around the northern end of the Thumb, and merged with it to form the larger lake known as Arkona—the first lake to fill a part of the Lake Huron basin. (Figure 7.) Lake Arkona endured for a long time, as is shown by the height and strength of its beaches and the size of the river deltas which were built into it and were not wholly destroyed by powerful later events. That the lake was large and deep and that the ice front stood far to the north and east, is also shown by the strong gravelly beaches which must have been made by waves that had a long “fetch” on shore. The beaches show that Arkona, the largest lake to occupy the Erie basin, was nearly three times as large as Lake Erie. It extended northward as far as Gladwin, Michigan, and eastward forty to fifty miles east of Buffalo, New York, and received from the east the waters of the long narrow ice border drainage covering the Finger Lakes region. It was the first lake to make definite beaches in Ontario, along the southern edge of the Ontario nunatak around which the ice had separated into two independent lobes—one in the

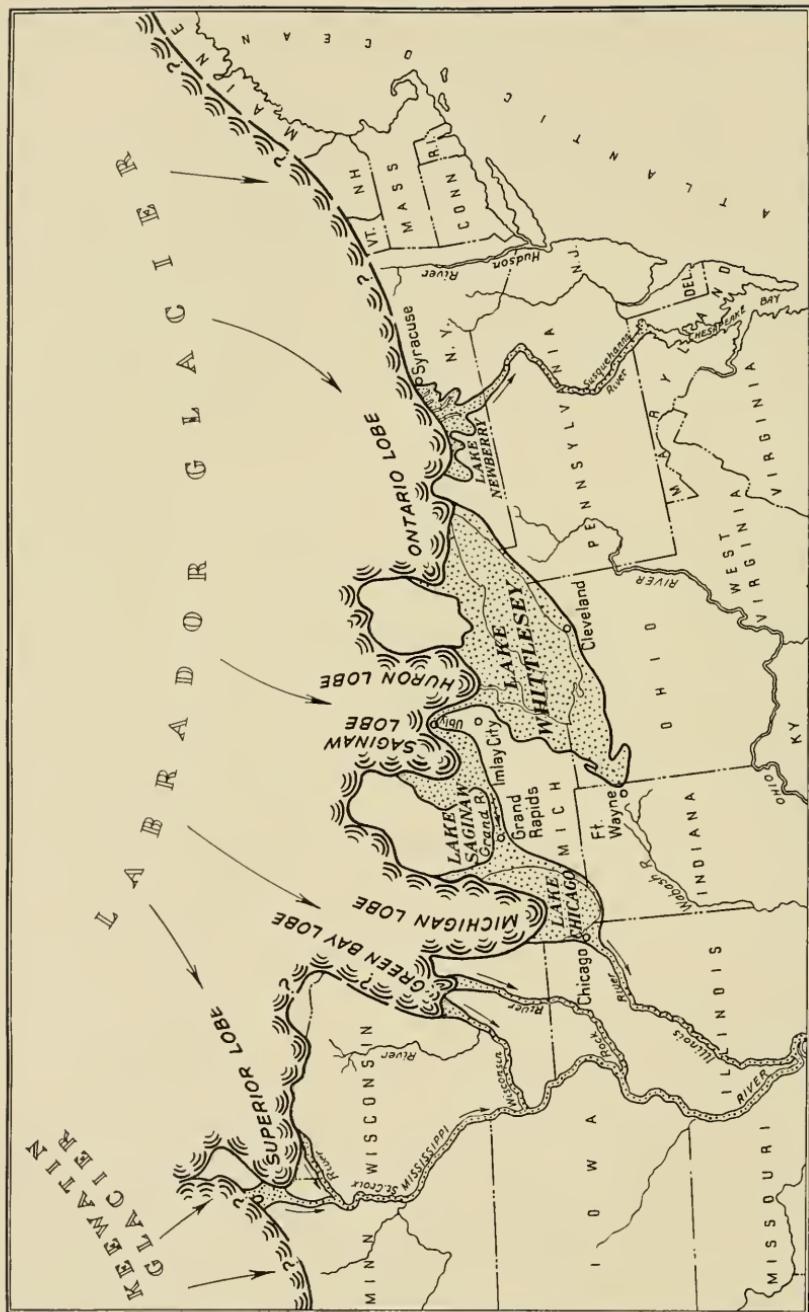


FIGURE 8.—GLACIAL LAKES WHITTLESEY, SAGINAW, CHICAGO AND NEWBERRY

UBLY OUTLET OF WHITTLESEY; GRAND RIVER; OUTLET OF SAGINAW; SUSQUEHANNA RIVER OUTLET OF LAKE NEWBERRY; DRAINAGE FROM GREEN BAY ICE LOBE THROUGH THE ROCK AND WISCONSIN RIVERS, AND FROM THE SUPERIOR LOBE THROUGH THE BOIS BRULE AND ST. LOUIS RIVERS TO THE ST. CROIX AND MISSISSIPPI.
After Everett and Taylor.

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Erie and the other in the Huron basin. As the ice retreated Lake Arkona fell to lower levels, building beaches at each halt in the lowering process, and the outlet continued through Grand River to Lake Chicago.

EXPANDING LAKE CHICAGO

As Lake Chicago continued to receive the discharge through Grand River from Lake Saginaw and Lake Arkona, the lake increased in size, particularly to the eastward, so that the river entered it near Grand Rapids, rather than near the Indiana line as at the earlier stage. During the retreat of the Lake Michigan ice lobe the crescent-shaped lake had developed several large bays along its eastern border, near the present mouth of St. Joseph River, along the lower course of Kalamazoo River, and in the region west of Grand Rapids. The St. Joseph, Kalamazoo, and Grand rivers abandoned their former united course to the Kankakee, past South Bend, Indiana, and each, in the order named, became an independent stream entering a bay of Lake Chicago.

RESTORED LAKE SAGINAW; LAKE NEWBERRY

Then the ice made a powerful and rapid re-advance southward. It cut off the waters in the Saginaw area and restored Lake Saginaw to independence, but did not change its level or its outlet to Grand River. It cut off the waters in the Finger Lakes region of New York, to form independent Lake Newberry, and caused them to find an outlet through Lake Seneca and Susquehanna River. (Figure 8.) We know that it was a re-advance of the ice which caused these changes, because the high Port Huron moraine—built when the glacier halted—covers part of the Arkona beaches. As we trace the Arkona beaches we find them suddenly disappearing under the Port Huron moraine, south of Cass City, Michigan, but they re-appear at the same level farther north in the Thumb area and thus very evidently are buried under the moraine in the intervening miles.

LAKE WHITTLESEY

Advance of the ice raised the level of the Arkona waters about forty-four feet and ushered in a new lake which is named Lake Whittlesey, for an early Ohio geologist. (Figure 8.) That Lake Whittlesey lasted for a long time is shown by the fact that it had time to fill in the bays and to build one of the strongest, straightest beaches in the lake region. The beach was used as a highway by Indians, and later by white men, from the time of the earliest Indian travel. In a direct line like a railway embankment, it crosses the valleys of creeks that formerly entered Lake Arkona, and in places it stands twenty to twenty-five feet above the old valley floors to the south. Such a strong beach must have been made by rapidly rising water moved by powerful waves. The material for it was torn from the earlier-built Arkona beaches, but when the Whittlesey waters were so deep that bottom water was below the level of wave action the Arkona beaches were protected from wave cutting and thus preserved. Rivers flowing into lakes Maumee and Arkona built deltas into the lakes, but deltas and stream valleys were drowned by the rising Lake Whittlesey. Thus, at first the shore had many wide estuaries into the heads of which the rivers then built new deltas, as streams are now filling the headwater levels of the drowned bays and estuaries of the Atlantic coast from Maine to Virginia. But the new deltas above and back of the old did not bulge into the lake beyond the beach, hence the peculiar condition of deltas of Whittlesey time fitting into the beach like insets in a mosaic. Gravel operators who procure gravel from this old beach often find the gravel cut out by the fine material of the inset deltas. However, near Alden, New York, a small delta made by a stream flowing into Lake Whittlesey buried the eastern end of the Arkona beaches; and in Canada glacial rivers developed such strength that they built deltas along the northern shore. The location of the ice barrier which retained this lake has been traced more precisely than

THE GLACIAL LAKES

that of any of the other glacial lakes, so that the position of the ice front is known from Lake Michigan near Muskegon, Michigan, to the Genesee valley in western New York. Parts of the moraine which the ice built along its front were laid in the deep water of lakes Saginaw and Whittlesey. These sections were washed over and are not so pronounced a feature of the landscape as the high morainic jumble of hills made elsewhere by the ice in this, its most powerful advance and longest stand in the area of the Great Lakes.

Although the advancing ice closed the broad strait that had made Lake Saginaw a part of Lake Arkona, and separated these lakes, an outlet for Lake Whittlesey was developed past the site of Ubly in Huron County, Michigan, which carried the waters of Lake Whittlesey into the lower Lake Saginaw and thence to Grand River, Lake Chicago and the Mississippi.

LAKE WAYNE

Again the ice retreated, and in the climax of this retreat the waters fell abruptly eighty to eighty-five feet and collected in a lake known as Wayne, causing the reunion of Lake Saginaw with the larger lake to the east. The boundaries of Lake Wayne have not been continuously traced, but it is so named because of the strength of the beaches at this elevation near Wayne, Michigan. Inasmuch as an outlet lower than the Grand River outlet has been found near Syracuse, New York, it is probable that for the first time the glacial lakes had an eastern outlet to the Hudson River valley. This outlet shows that the waters fell over cliffs in the hills south of Syracuse, making falls as high as Niagara. It is also possible that the outlet may have been to the north, past the ice front to the region of Little Traverse Bay in Michigan, and thence to Lake Chicago; but evidence supporting this theory is not as conclusive as that for an eastern outlet. Also, Lake Saginaw may have had a northern outlet and Lake Wayne an eastern outlet. (This is just one of the many interesting perplexities

in the lake history.) It is apparent that a lake corresponding to Lake Arkona may have existed again for a short time when the Whittlesey waters reached the former Arkona level on the way down to the level of Lake Wayne.

EARLY LAKES OF THE SUPERIOR BASIN

About this time the ice lobe in the Superior basin had retreated north of the drainage divide, and five small lakes had formed along its borders. The largest of these, glacial Lake St. Louis (formerly called Lake Upham), was held between the Superior ice lobe on the east and the Keewatin ice on the west and covered the central drainage basin of St. Louis River, south of the Mesabi Range in Minnesota. Its outlet was down St. Louis River to the ice border, thence along the border to Kettle River, a tributary of St. Croix River. A second small lake formed in southeastern Carlton County, Minnesota, in the extreme western end of the Lake Superior basin. It has been named Lake Nemadji, as Nemadji River flows across its bed. Its outlet was westward to Moose Lake and Kettle River and to the St. Croix. In northern Douglas and Bayfield counties, Wisconsin, glacial Lake Brule covered about twenty square miles of the drainage valley of Bois Brule River. Its outlet was southward through St. Croix River to the Mississippi. At first it received drainage along the ice border from as far east as Baraga County, Michigan, but later the border drainage expanded into two other lakes, Ashland and Ontonagon. Lake Ashland covered several townships in northeastern Ashland County, Wisconsin, and extended to the eastern slope of Bayfield Peninsula. It was separated from Lake Brule by the highlands of the Copper Range but had an outlet across Bayfield Peninsula into Lake Brule. Farther east, glacial Lake Ontonagon occupied much of the drainage basin of Ontonagon River, south of the Copper Range in the Northern Peninsula of Michigan. Its outlet was the peculiar narrow channel, one-eighth to one-fourth of a mile wide and

THE GLACIAL LAKES

twenty to forty feet deep, leading from the present Lake Gogebic to Presque Isle River, thence in a northward loop almost to Lake Superior, thence westward again past Bessemer, Michigan, and Saxon, Wisconsin, into glacial Lake Ashland in the northwestern corner of Iron County, Wisconsin. The ice border drainage from Baraga County eastward drained southward into glacial Lake Chicago. The old beds of glacial lakes Brule, Ashland and Ontonagon are the fertile agricultural lands in an otherwise rocky infertile region.

LAKE WARREN

At length came another oscillation of the ice, and the eastern outlet for the lakes in the Huron-Erie basin was closed. The lake waters again were raised above the level of Lake Wayne and created the lake known as glacial Lake Warren. (Figure 9.) It was at the level of Lake Saginaw and once more deprived that lake of its independence. But despite the southward oscillation of the ice front which closed the eastern outlet, the ice had melted far enough north so that now the lakes entered the Ontario basin. The outlet returned to Grand River, and the waters from all the lakes, including the waters of the Finger Lakes region of New York and of Lake Simcoe in Ontario, drained to the enlarged Lake Chicago and thence to the Des Plaines-Illinois, or Chicago, outlet to the Mississippi. Lake Warren repeated the history of Lake Whittlesey: it was the result of an ice advance, its waters were raised above the level of its immediate predecessor lake, and its violent storm waves tore into the material of the Lake Wayne beaches to build its own strong, sandy and gravelly beaches, which also have been used by men for travel routes.

LAKE DULUTH

In the Superior basin the ice retreated step by step until the western end of the basin was uncovered. Lakes St. Louis and Nemadji drained into Lake Brule, and all became a part of Lake Duluth—the ancestral Lake Superior. This was a cres-

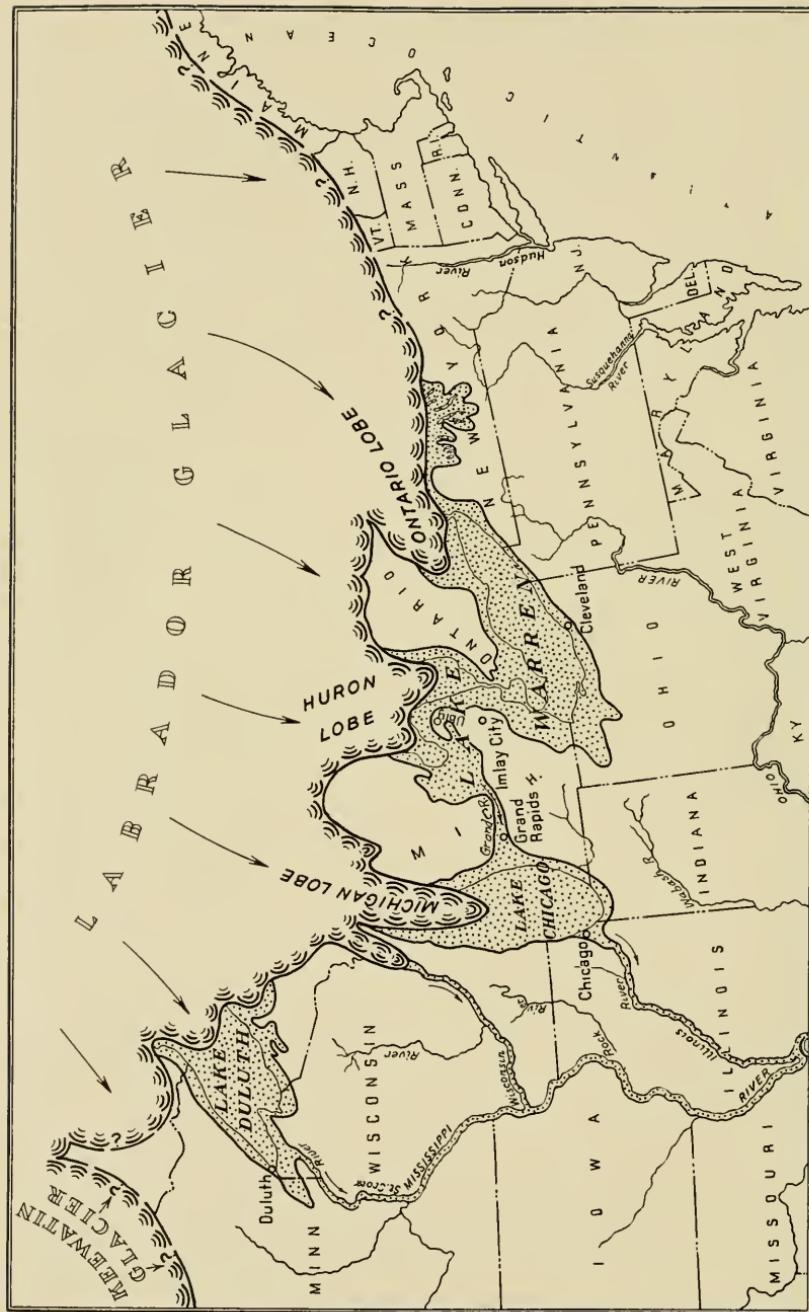


FIGURE 9.—GLACIAL LAKES WARREN, CHICAGO AND DULUTH

GRAND RIVER OUTLET OF WARREN; ILLINOIS RIVER OUTLET OF CHICAGO; ST. CROIX RIVER OUTLET OF DULUTH;
WISCONSIN RIVER DRAINAGE OF GREEN BAY LOBE.
After Leverett and Taylor.

cent-shaped lake around the end of the Superior lobe, which drained through the old Lake Brule outlet to St. Croix River and the Mississippi. Lake Ontonagon was lowered about 200 feet, and its bed became land, but narrow bays of Lake Duluth extended a few miles up each of the tributaries of Ontonagon River south of the Copper Range.

LAKE ELKTON

Powerful as were Lakes Warren, Chicago and Duluth, they also gave way to lower lakes, as the ice once again retreated and drew the lake waters down. Lowering was slow and halting, and at each halt the lake had time to make a beach. At two such halts prominent beaches, the Grassmere and Elkton, were built. During that period the waters of the Huron and Erie basins were connected by a broad shallow strait across the site of the St. Clair and Detroit rivers and Lake St. Clair. As the lake level fell parts of the strait became so narrow that the waters flowed through it with a river-like current across the submerged Port Huron moraine, eleven miles south of Port Huron, Michigan. This stream may be considered the ancestral St. Clair River. Through it the waters of Lake Saginaw were brought to the level of the next lake in the Erie basin—glacial Lake Elkton (formerly named Lake Lundy.)* (Figure 10.)

When the lakes settled to the Elkton level the Grand River outlet was abandoned, because a lower outlet was uncovered eastward through the Marcellus-Cedarvale channel which crosses the hills southwest of Syracuse, New York. This outlet passed over the Niagaran escarpment and was shifted westward over it from place to place as the water level lowered. The outlet stream falling over the escarpment made falls as high and imposing as Niagara, and although little or no water now descends over these "fossil" cataracts, they add to the

*Dr. Frank Leverett changed the name of this lake from Lundy to Elkton in 1919.

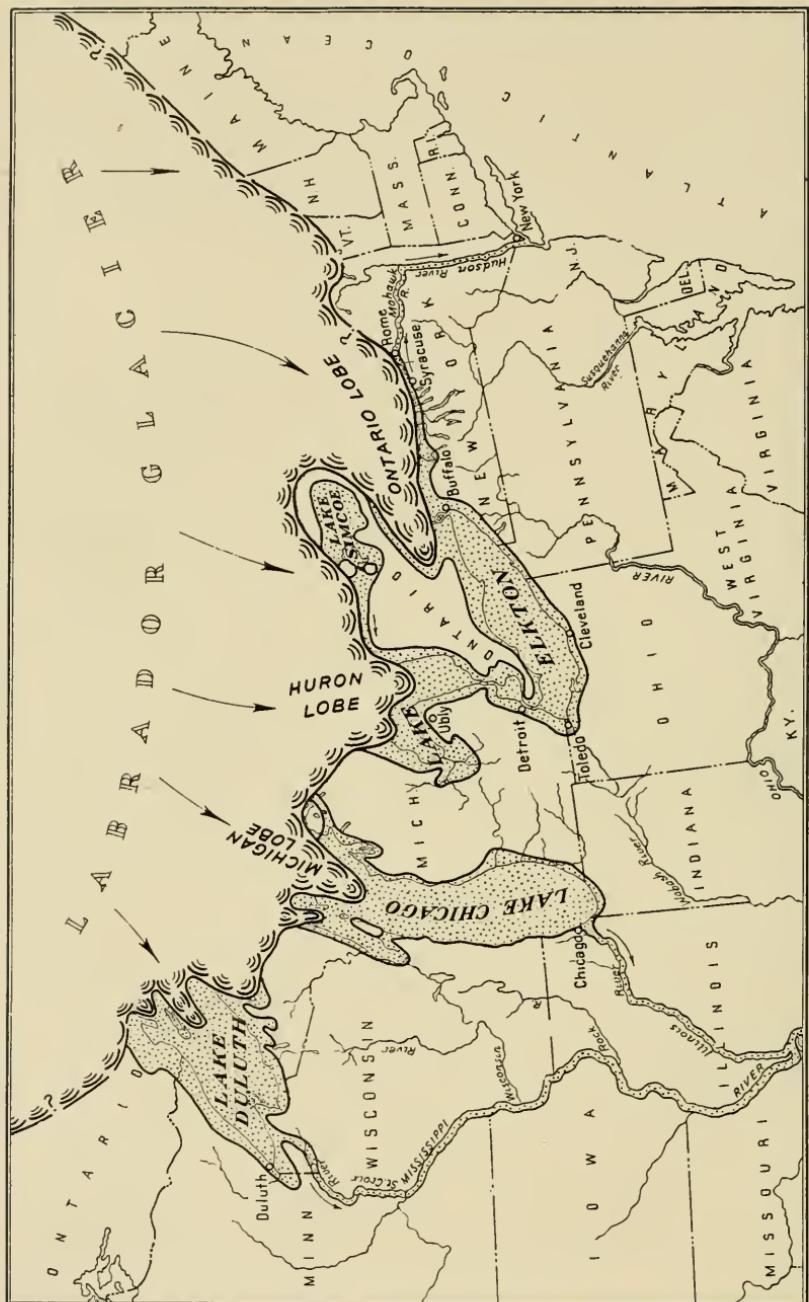


FIGURE 10.—GLACIAL LAKES ELKTON (FORMERLY LUNDY) SIMCOE, CHICAGO AND DULUTH
 MOHAWK RIVER OUTLET OF ELKTON; ILLINOIS RIVER OUTLET OF CHICAGO; ST. CROIX RIVER OUTLET OF DULUTH.
After Leverett and Taylor.

grandeur of the scenic beauty in western New York, particularly near Jonesville and in the Blue Hills.

At the close of Lake Elkton time the ice had retreated northward far enough so that the Great Lakes began to shrink into the limits of the ancient river basins and to assume somewhat their present appearance. In the Superior basin Lake Duluth extended eastward to the highlands of Keweenaw Peninsula and the Huron Mountains, and westward and northward beyond Duluth, Minnesota, and Fort William Ontario, but its outlet was still through the Bois Brule-St. Croix River to the Mississippi.

Lake Chicago had enlarged northward until it occupied Green and Traverse bays. It received considerable drainage from the ice fronts in the Northern and Southern peninsulas of Michigan and continued to drain to the Mississippi. Lake Saginaw had merged with Lake Elkton; a large lake in the Simcoe basin of Ontario was connected with Lake Elkton by a stream flowing along the ice front; the western end of the Ontario basin was occupied by the eastern part of Lake Elkton, extending in long narrow bays around the Ontario ice lobe. Overflow discharged eastward over high cataracts and drained along the ice border past Syracuse and down the Mohawk valley to the Hudson. This drainage channel is known as the Syracuse outlet.

The effect of lowering the outlet through the Syracuse channel was to increase the power of the currents flowing over the old submerged moraines which marked the former positions of the ice front south of Port Huron and which had acted as barriers holding up the waters in the Saginaw and Huron basins. These moraines are south of Port Huron, at Detroit, and near Trenton—southwest of Detroit. The morainic material was easily cut through by several streams,

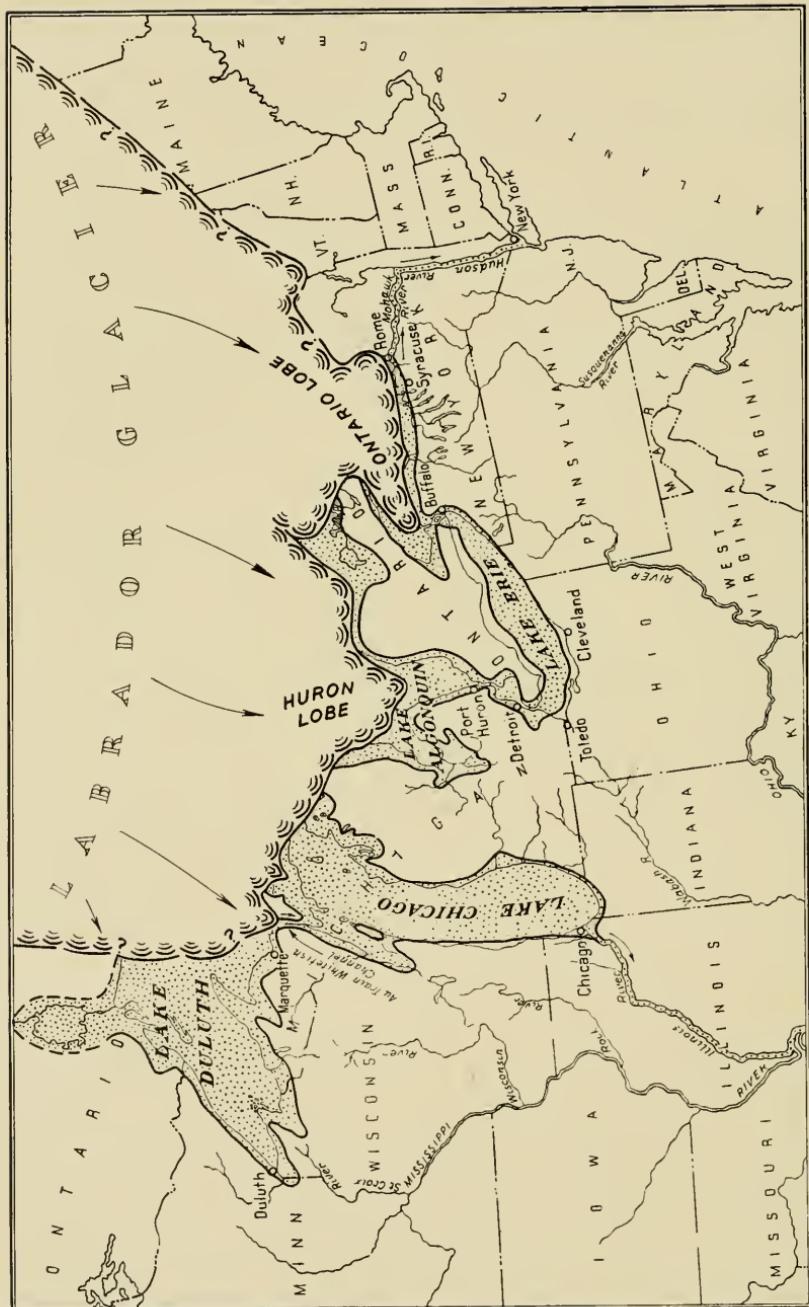


FIGURE 11.—GLACIAL LAKES DULUTH, CHICAGO, AND EARLY ALGONQUIN; INDEPENDENT AU TRAIN AND WHITEFISH RIVER OUTLET OF DULUTH; ILLINOIS RIVER OUTLET OF CHICAGO; MOHAWK AND HUDSON RIVER OUTLET OF ERIE-ALGONQUIN.
After Leverett and Taylor.

as for a time two St. Clair rivers flowed in parallel courses, and Detroit River resembled a wide loosened braid of many strands. But in time the currents chose the eastern channels and took almost their present courses. When these rivers developed, the lakes in the Huron and Erie basins were finally separated, and a fairly stable condition was established. This initiated perhaps the most interesting episode in the long lake history—the beginning of glacial Lake Algonquin, the largest of the glacial lakes and the last to be controlled by the ice sheet. Up to this time the important lakes were in the Erie and connecting basins; from now on the northern lakes become important.

EARLY LAKE ALGONQUIN; LAKE TONAWANDA

The early Lake Algonquin (Figure 11) occupied only the southern part of the Huron basin. The outlet at Port Huron discharged its waters southward into Lake Erie, thence along the ice front in the Ontario basin, past Syracuse and down the Mohawk valley to the Hudson. Correlative with it were lakes Chicago and Duluth in the west and Lake Tonawanda in New York. When the ice front withdrew back of the Niagaran escarpment and the waters in the Ontario basin began to lower, a broad shallow lake was left for some time, stretching for fifty miles east of Buffalo, New York, and eight or ten miles west of the present location of Niagara Falls. Tonawanda Creek now flows on the bed of this short-lived lake which we know as glacial Lake Tonawanda.

The waters of Lake Duluth reached Lake Chicago by flowing southward from near Marquette, Michigan, through the rocky channel now used by the short northward-flowing Au Train River and the longer southward-flowing Whitefish River, having abandoned the higher western outlet to St. Croix River. Lake Chicago still used the Chicago outlet, via the Des Plaines-Illinois-Mississippi rivers. The ice later withdrew from the high lands west of Alpena, Michigan, and

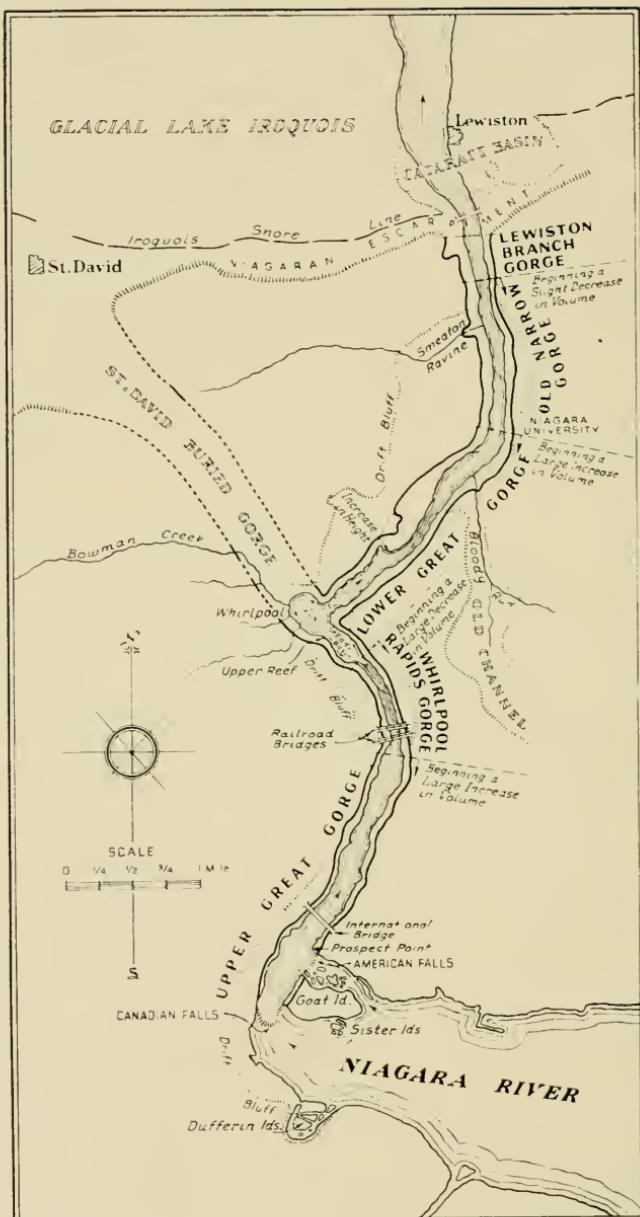


FIGURE 12.—DIAGRAM OF NIAGARA RIVER GORGE
SHOWING RELATIONSHIPS TO THE LAKES.
Modified from Gilbert—U. S. Geological Survey, Niagara Folio.

CUTTING NIAGARA'S GORGE

ended the independence of Lake Chicago, uniting it across northern Michigan with the early Lake Algonquin. However, as the two lakes were at the same level, it is probable that for a time both the Chicago and the Syracuse outlets were used.

NIAGARA RIVER AND THE BIRTH OF THE FALLS; BEGINNING OF INDEPENDENT LAKE ERIE

At this period in the Lake drama Niagara River comes on the stage to play an important part. When the ice of the Ontario lobe withdrew far enough north so that the melt waters fell below the level of the Niagaran escarpment, the overflow from lakes Erie and Tonawanda fell over the rocky ledge near Lewiston, New York; then Niagara Falls was born, and Lake Erie became independent. No longer fed by glacial streams, Erie waters became warm and gradually became populated with fresh-water fish. At first the water descended in a great cascade, but in a short time a pool, Cataract Basin (Figure 12), was scoured at the base of the cascade, and undercutting of the limestone ledge followed. Four other spillways northward from Lake Tonawanda were in use, but the spillway at Lewiston was the largest, and as it also received the overflow from Lake Erie it could cut faster. In time it drained Lake Tonawanda westward and caused the abandonment of the spillways at Holly, Medina, Gasport and Lockport, New York, leaving them as short gorges in the escarpment carrying small streams with cascades. Lake Tonawanda was drained, until now all that is left of it is the broad part of Niagara River above Goat Island.

During the life of early Lake Algonquin, about 2,000 feet of the Niagara gorge was cut back from the escarpment. This section is known as the Lewiston Branch Gorge. Ordinarily a stream flowing from a lake has no cutting tools with which to deepen its channel, for rock debris carried into the lake is left on the bottom, and the outlet stream flows clear. Niagara River has always carried clear water, but it

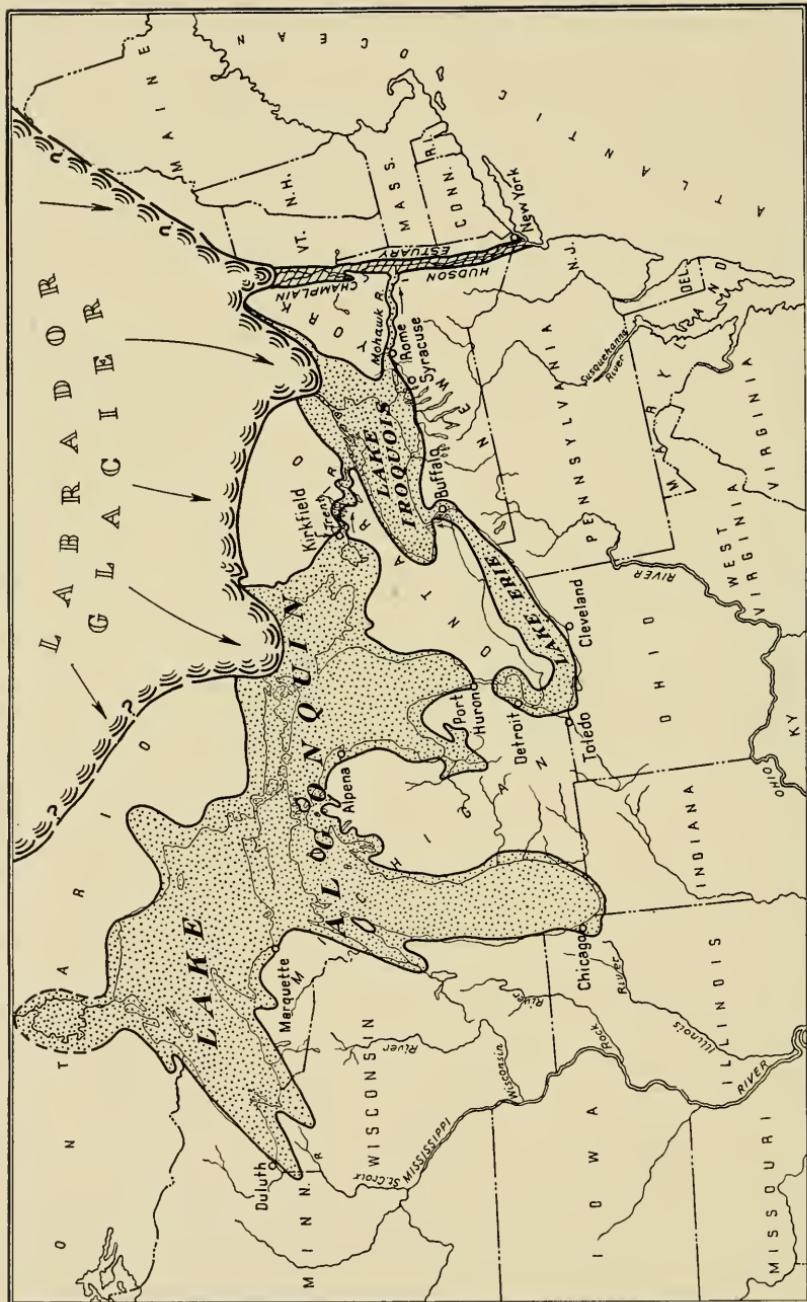


FIGURE 13.—GLACIAL LAKES ALGONQUIN AND IROQUOIS; LAKE ERIE
TRENT RIVER OUTLET OF ALGONQUIN; MOHAWK RIVER OUTLET OF IROQUOIS-ERIE TO THE HUDSON-CHAMPLAIN
ESTUARY AND THE ATLANTIC OCEAN.
After Leverett and Taylor.

flows northward over a gently southward-sloping bed of thick limestone. When the water of the river falls over the escarpment it drops with such force that it breaks up the rocks below and thus gives the stream below the falls powerful cutting tools. Under the limestone are thick beds of soft shales—the same shales in which Green and Georgian bays are carved. Below the shales is a thin hard limestone which furnishes heavy tools when its fragments fall into the river; under this is another layer of soft shales, and then a resistant sandstone about at the water level below the falls. The water dashing against the rocks at the base of the falls hurls the fragments upward against the soft shales, smashing, biting, breaking into them, and so undermining the sandstones and limestones. The thick heavy upper limestone is thus undercut until it resembles an overhanging cornice; it becomes top-heavy and then huge masses of it break loose and fall into the maelstrom below, adding to the tools already there. This process of undercutting the shales and breaking off the unsupported limestone cornice has been going on ever since the first water dashed against the shales in the escarpment cliff at Lewiston, eighteen to twenty thousand years ago, and has been the most important factor in cutting the Niagara gorge. The gorge has been deepened by the river with rock-fragment tools supplied from the fallen sandstone and limestone blocks, but the varying widths and other characteristics of the gorge are a part of the story of the lakes.

THE SECOND STAGE OF LAKE ALGONQUIN; LAKE IROQUOIS; LAKE ERIE

The early stage of Lake Algonquin passed when the ice retreated far enough to open an outlet lower than the outlets at Port Huron and Chicago. When the level of the lakes became stationary at the level of this new outlet the second stage of Lake Algonquin was established, and it endured for a long time. (Figure 13.) As early Lake Algonquin was

passing into the second stage, the ice in the Ontario basin had melted so far to the northeast that the long narrow body of water between the ice and the Niagaran escarpment increased to a lake overflowing the basin. This body of water has been named Lake Iroquois and is the ancestor of Lake Ontario. Retreating from the vicinity of Syracuse, the ice uncovered a still lower outlet near Rome, New York, through which the waters of Lake Iroquois spilled down the Mohawk valley to the Hudson and deepened the channel which centuries later was to serve as a part of the Erie Canal. Lake Iroquois was fed not only by the waters of the melting Ontario ice lobe but also by the overflow from the vast second Lake Algonquin, which discharged through a lower outlet than the Port Huron-Lake Erie-Niagara River route. All the waters of the upper lake basins—Superior, Michigan, Huron, Saginaw and Georgian Bay—were connected in a broad expanse of lake. Its shores extended well beyond the borders of the present waters occupying those basins, and it covered the eastern part of the Northern Peninsula of Michigan, except for a few small islands. The entire overflow passed eastward through the low col in the vicinity of Kirkfield, Ontario, down Trent River to the Ontario-Lake Iroquois basin—a channel known as the Kirkfield-Trent River outlet. Thus, when Lake Algonquin fell to the level of the Kirkfield outlet its waters reached the Atlantic Ocean at New York through Lake Iroquois, Mohawk River and the Hudson valley. The Hudson valley was then a marine estuary, drowned when it was flooded by the rising Atlantic Ocean. Lake Erie was a small independent lake in the eastern part of the Erie basin, no longer fed by the waters of melting ice, and was somewhat below the level of the lake today. It had as tributary a stream which flowed from the swampy region which is now Lake St. Clair, through the channel (perhaps a swampy slough) of Detroit River, and across the western floor of the old lake. During this period Niagara River, receiving only the overflow from this small

CRUSTAL MOVEMENTS OF THE EARTH

Lake Erie, could cut but a narrow gorge—the part beginning about 2,000 feet above the mouth of the gorge and extending to the bend just north of Niagara University, a distance of about one and one-eighth miles—known as the Old Narrow Gorge.

CRUSTAL MOVEMENTS OF THE EARTH

Up to this time the story of the lakes has been a tale of the carving of valleys by pre-glacial rivers, of the coming of the ice and the consequent deepening and widening of these valleys, of melting ice and filling of the basins with glacial waters. Now another force, which all the time had been gently active, becomes most important in the story.

The rock crust of the earth rests upon a more-or-less plastic, yielding interior. Thus, it is probable that so great a mass of ice covering the northern half of the continent and weighing millions of tons must have burdened the land surface and depressed it far below the level it had attained in the highlands where the glaciers first developed; also, it is plausible that as the ice melted the land would gradually rise again when relieved of this weight. From the evidence that the lakes have left us, this seems to be exactly what happened.

As lake surfaces are level, the beaches and strand lines must be essentially horizontal when made. However, studies of the glacial lake beaches show that, although their southern parts are horizontal, as we follow them northward they gradually rise in elevation. Only an uplift of the continent after the beaches had been made could so disturb their horizontality. The Whittlesey and Warren beaches are tilted upward toward the north, showing that the depressed portion of the continent started to be re-elevated when the ice had retreated half-way across the lake region. It is notable that the places of initial tilt of the beaches of each of the lakes, which are well defined and readily observed on opposite sides of the lakes, lie on practically straight connecting lines. These are known as hinge

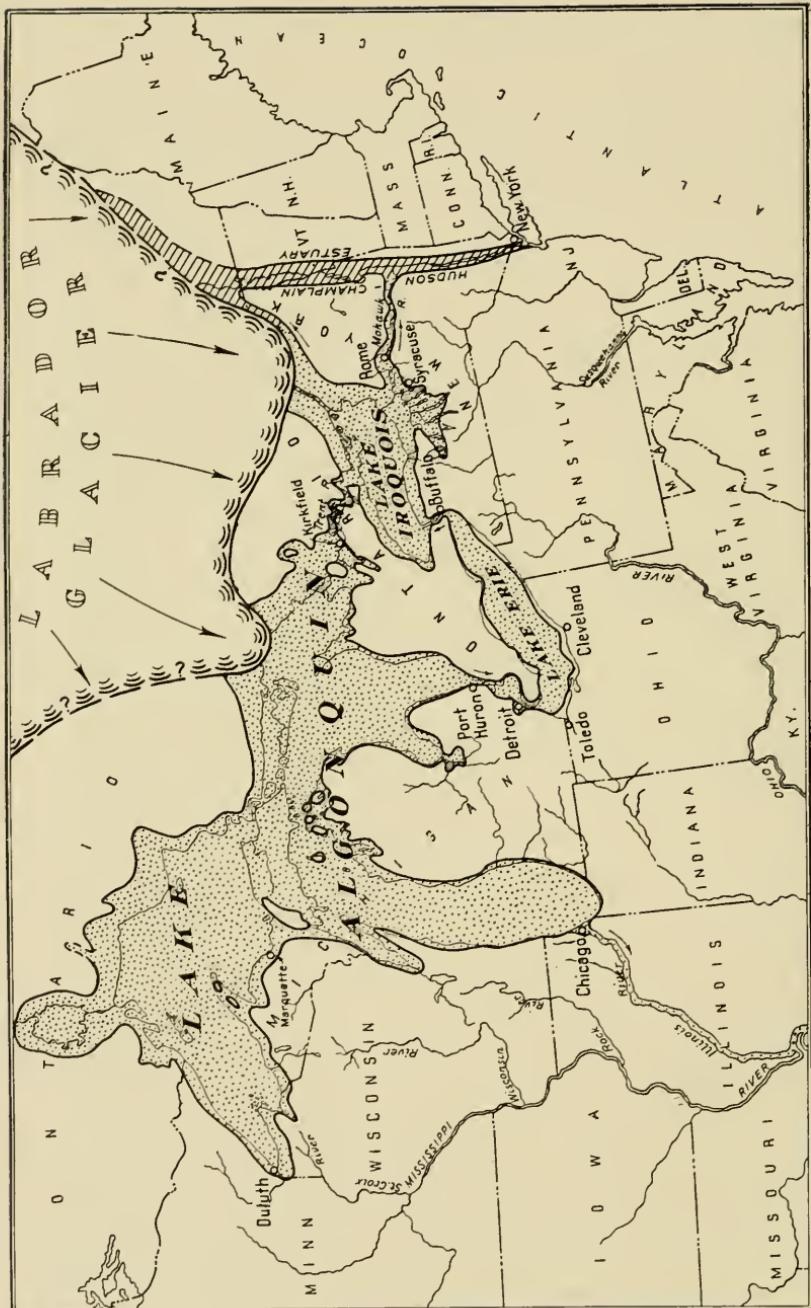


FIGURE 14.—GLACIAL LAKES ALGONQUIN ANDIROQUIS; LAKE ERIE
THREE-OUTLET STAGE OF ALGONQUIN—ILLINOIS RIVER, PORT HURON, AND TRENT RIVER OUTLETS; MOHAWK RIVER AND
ST. LAWRENCE OUTLETS OF IROQUIS TO HUDSON-CHAMPLAIN ESTUARY.
After Leverett and Taylor.

MORE WORK OF NIAGARA RIVER

lines, north of which the beaches are upcanted somewhat as a partly-opened trap door. The hinge line north of which the continent first uplifted extends from Ashtabula, Ohio, northwestward across Lake St. Clair, and bends to Lake Michigan west of Grand Rapids. South of that line the Lake Whittlesey beaches are horizontal; north of it they are up-tilted. That the uplift was somewhat spasmodic is shown by the fact that the Lake Warren beaches are up-tilted north of another hinge line about fifteen miles north of and parallel to the Whittlesey hinge.

By these deformed beaches we know that the forces of continental uplift were active even before the time of Lake Algonquin, but they had played no very important part as yet in the development of the lakes. By the time the Kirkfield outlet of Lake Algonquin was well established, and a river wider than the St. Clair had scoured a broad channel down the Trent River valley, and the lake had made well-defined beaches and other shore formations, the continent began to rise more rapidly; then the waters of the lakes were spilled southward out of their basins and again found their old outlets past Port Huron and Chicago; and for a time Lake Algonquin had three outlets: to Lake Iroquois, to Lake Erie, and to Mississippi River through the old Chicago outlet. (Figure 14.) Spilling the waters on the south shores destroyed the beaches of the Kirkfield stage in Michigan, but they are preserved around Duluth and in the Ontario areas. The down-cutting, and therefore lowering, of the outlet past Port Huron diverted the overflow from the Chicago outlet, so that in the latter part of this stage Lake Algonquin was drained through lakes St. Clair, Rouge and Erie. Lakes St. Clair and Rouge were small transitional lakes in depressions of the former strait connecting the Huron and Erie basins during Lake Elkton time, and now held the Algonquin overflow. They were large enough and lived long enough to make faint but well-defined beaches. The uplift raised the level of the Rome,

New York, outlet of Lake Iroquois and caused the water to be ponded back on the southern shores, but it was not high enough to cause a reversal of flow back into Lake Erie. At this stage Lake Iroquois made its strongest beach.

MORE WORK OF NIAGARA RIVER

The early increase in volume in the rejuvenated Lake Erie increased the activity of Niagara River: a greater volume of water flowed over the falls, and a wider gorge was cut—that part of the gorge extending from the bend north of Niagara University up-stream as far as the head of Foster Rapids. When the Chicago outlet was abandoned and all the water of the upper lakes poured over Niagara, the wide gorge from the head of Foster Rapids to the upper edge of the Eddy Basin above the Whirlpool was made. Together these parts of the gorge are known as the Lower Great Gorge. (Figure 12.) Curiously, the Whirlpool is not a part of the gorge proper. Its story is actually older than that of the gorge in which it now lies. At some time before the last ice invasion, a river flowing from southeast to northwest had plunged over the Niagaran escarpment at the site of the little Canadian town of St. David. Like the Niagara, this river, which has been named St. David, cut a gorge back from the escarpment as far as the Eddy Basin just above the Whirlpool. The on-coming glacier destroyed the river and filled its gorge with rock debris (drift), which then became considerably cemented together although not as solid as rock. Later, when the Niagara had cut back to the old buried gorge, the northeast wall of the gorge supporting the falls became thin and crumbled, giving the waters access to the less-resistant material filling the old channel. The waters of Niagara, plunging with great force and volume, soon scoured away the glacial debris, swirled and hurled its heavy tools northwest into the buried gorge until it had made the Whirlpool. The depth of the Whirlpool is due in part to the depth of the buried gorge

THE RECORDS OF ALGONQUIN TIME

which the Niagara resurrected. The Lower Reef, at the outlet of the pool, is the remnant of the breached wall of the old gorge; the Upper Reef marks the site of the ancient St. David's Falls. At present the current, dashing along the right side of the gorge, swirls around to the left in the pit of the Whirlpool, swings back upstream into the Eddy Basin and then downstream over the Lower Reef, cutting deeper and deeper into the soft shale bed of the pool and also cutting against the drift fill of the ancient St. David's Gorge. A small stream, Bowman Creek, enters the Whirlpool from the old gorge and carries its contribution of rock waste as cutting tools for the Niagara. This section of the gorge, made during the two-outlet stage of Lake Algonquin, is two miles long, showing the long time that the second stage of this lake existed.

THE RECORDS OF ALGONQUIN TIME

The rising deepening waters of Lake Algonquin, whose powerful waves beat with force against the shores, built strong beaches which are marked by well-defined cliffs and beach ridges in the landscape about the present three upper lakes—Michigan, Superior and Huron. As one drives toward the shores of these lakes, the highway leads from rolling morainic uplands, down over cliff to terrace, and across the several beaches of Lake Algonquin. In places later lakes have cut away the Algonquin beaches, but in the main these beaches are the high cliffs set some distance back from the present lake shores. Tracing of the beaches shows that the Chicago outlet is choked by the Algonquin beach; that the tip of the Southern Peninsula of Michigan, north of Indian River and Petoskey, was an archipelago; and that only the highest points of Keweenaw Peninsula were above water as islands. The great inland lakes of Michigan—Torchlight, Charlevoix, Walloon, Mullet, Douglas, Burt and others—with their high-cliffed terraces, are remnants of Lake Algonquin. The "in-



Photo by Michigan Department of Conservation

PLATE 4.—ARCH ROCK, MACKINAC ISLAND

A SEA ARCH CUT IN LIMESTONE OF THE ALGONQUIN SHORE. THE NIPISSING BEACH BELOW HAS BEEN DESTROYED BY MODERN WAVE ACTION.

land route" of lakes and low portages between Cheboygan and Petoskey is a channel of the Algonquin archipelago. The interesting cliffted scenic beauty of Mackinac Island was produced by the work of the ancient lakes. During Algonquin time Mackinac Island was triangular in shape and only about three-fourths of a mile long, rising eighty feet above the lake level. On its shores the beating waves of Lake Algonquin carved Sugar Loaf and Arch Rock. From this small ancient island Mackinac slopes by cliff and terrace to the present lake level. Each terrace and its backing cliff represents a level of the ancient lakes as well as a step in the slow uplift of the continent. In places the waters of later lakes have cut into



Photo by Michigan Department of Conservation

PLATE 5.—SUGAR LOAF ROCK, MACKINAC ISLAND

A LIMESTONE REMNANT OF THE ANCIENT ALGONQUIN SHORE, NOW FAR INLAND AND ABOVE LAKE LEVEL.

the beaches, so that the cliffs now rise sheer from the Huron to the old Algonquin shore, but the general view of the island is of land rising by great steps from Lake Huron.

Interesting and arresting are these raised beaches, with their arched rocks, wave-cut cliffs, sea caves and grottos, and shingle beaches high above lake level; they tell a story not only of rising and falling water but of a rising land. If we sail along the lakes we see the interesting rocks, like little ships, cut from the mainland and jutting into the lake at the tip of the Thumb of Michigan—at Pointe Aux Barques. They are cut in the rocky shore cliff of Lake Algonquin, which at the Pointe is only ten feet above the level of Lake Huron; but when we reach Mackinac we find the same shore—which we



Photo by Michigan Department of Conservation

PLATE 6.—POINTE AUX BARQUES, SEA CAVES AND ARCHES
CUT IN THE MARSHALL (MISSISSIPPIAN) SANDSTONE OF THE ALGONQUIN
SHORE; HURON COUNTY, THUMB OF MICHIGAN.

could have followed all the way on the mainland—to be 194 feet higher. The elevation of this beach at Port Huron is 607 feet above sea level, at Mackinac 801 feet, near Munising in the Northern Peninsula 948 feet—341 feet higher than at Port Huron; and on Keweenaw Peninsula west of Calumet it is at 1,080 feet, rising to 1,100 feet near Mohawk and to 1,110 feet near Cliff. If we follow the beach eastward from Port Huron to the Kirkfield outlet, we find ourselves gradually mounting higher, until at Kirkfield, Ontario, the beach is 883 feet above sea level—276 feet above its Port Huron elevation. North of Georgian Bay evidence of the beaches shows that the country has been lifted 600 to 700 feet. The Algonquin beaches near Grand Bend, Ontario, on the eastern

shore of Lake Huron, at Richmondville on the western shore, at Standish near Saginaw Bay, and near Manistee on the eastern Lake Michigan shore, are at the same elevation, thus establishing the position of the Algonquin hinge line north of which the land has uplifted. At times uplift was slow and steady so that the beaches were actually split while forming, and several beaches of the lowering lake actually come together at a common point—just to add to the complexities.

The records made along the eastern boundary of the glacier during Lake Algonquin time have not been fully worked out; but when the ice sheet in the St. Lawrence valley had retreated to the northern edge of the Adirondack Mountains, a new outlet for Lake Iroquois somewhat lower than that at Rome, New York, was found, and a channel was scoured along the northern mountain slope toward Lake Champlain. Continental uplift shortened the life of this stage, which is known as Lake Frontenac.

When the ice barrier withdrew farther north the land was so low that the sea, which had gradually risen with the return to it of vast quantities of glacial waters, entered the valley of the St. Lawrence (as earlier it had entered the valley of the Hudson), filling the Ontario basin with ocean water, as is shown by the remains of marine or salt-water animals left in the deposits. This marine embayment has been named Gilbert Gulf.

As it must come to everything, an end came to Lake Algonquin. The barrier holding it to the highest level finally gave way when the ice retreated north of North Bay, Ontario, and opened an outlet even lower than the Kirkfield outlet. Then through a short river bordering the ice front the waters of the upper lakes poured into the marine gulf which had flooded the valleys of the St. Lawrence and Ottawa rivers, of Lake Champlain and Hudson River. This great marine estuary is known as the Champlain Sea. Evidence is lacking to determine the time duration of this, the Ottawa, stage of the

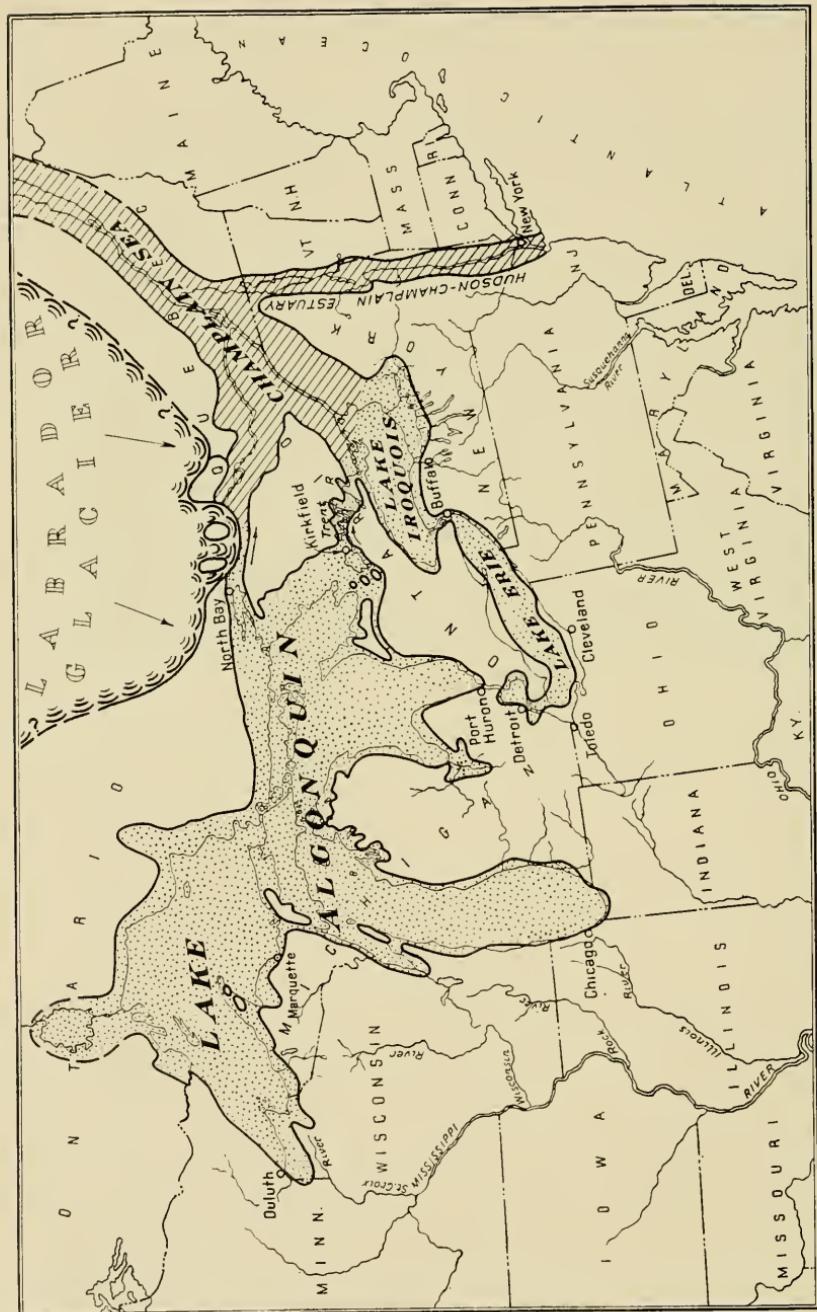


FIGURE 15.—FINAL STAGE OF GLACIAL LAKE ALGONQUIN; LAKE ERIE AND LAKEIROQUIS
 THE OTTAWA OR TRANSITION STAGE OF ALGONQUIN: OUTLETS THROUGH TRENT RIVER AND OTTAWA RIVER TO THE
 CHAMPLAIN SEA; MARINE INVASION OF THE ST. LAWRENCE VALLEY AND OF LAKE IROQUOIS; INDEPENDENT LAKE ERIE.
After Leverett and Taylor.

THE NIPISSING GREAT LAKES

lake, but it marks the end of Algonquin, the last of the glacial lakes (Figure 15), and was a transition to a new lake, for the waters fell to a lower level when the ice had completely withdrawn from the basin of the Great Lakes.

THE NIPISSING GREAT LAKES

When the ice was no longer a barrier the lakes were drawn down almost to their present levels in the five separate basins. The three upper lakes which occupied the Superior, Michigan, and Huron-Georgian Bay basins are known as the Nipissing Great Lakes. (Figure 16.) The beaches are strongest near the present Lake Nipissing, in Ontario near the North Bay outlet, hence the name. The col at North Bay was the lowest along the Nipissing shore, so the outlet was developed through it down the Mattawa River into the Ottawa—from which the sea had withdrawn. By the time the Mattawa-Ottawa River outlet was well established the land had risen so that the sea retreated eastward to the limits of a narrow estuary reaching up the St. Lawrence and Ottawa valleys to a short distance west of Ottawa. The Champlain-Hudson valley remained filled with marine waters. The old North Bay outlet at the present time is marked by lakes and swamps, with connecting dry valleys which show the marks of scour of a great river. It is the route by which Marquette, Allouez, Mesnard and other early Jesuit missionary explorers reached Georgian Bay and Lake Superior.

In the early stages the Nipissing lakes built beaches which have been nearly obliterated except in a small area near the northeast corner of Lake Superior. The strong beach we know as the Nipissing beach was made when the lake was rising, its waters being spilled on its southern shores as the continent continued to uptilt to the north. That the tilting was rather rapid is shown by the "greediness" with which this lake bit into the old Algonquin beaches where they had been cut as cliffs. In the area where the beaches are horizontal the

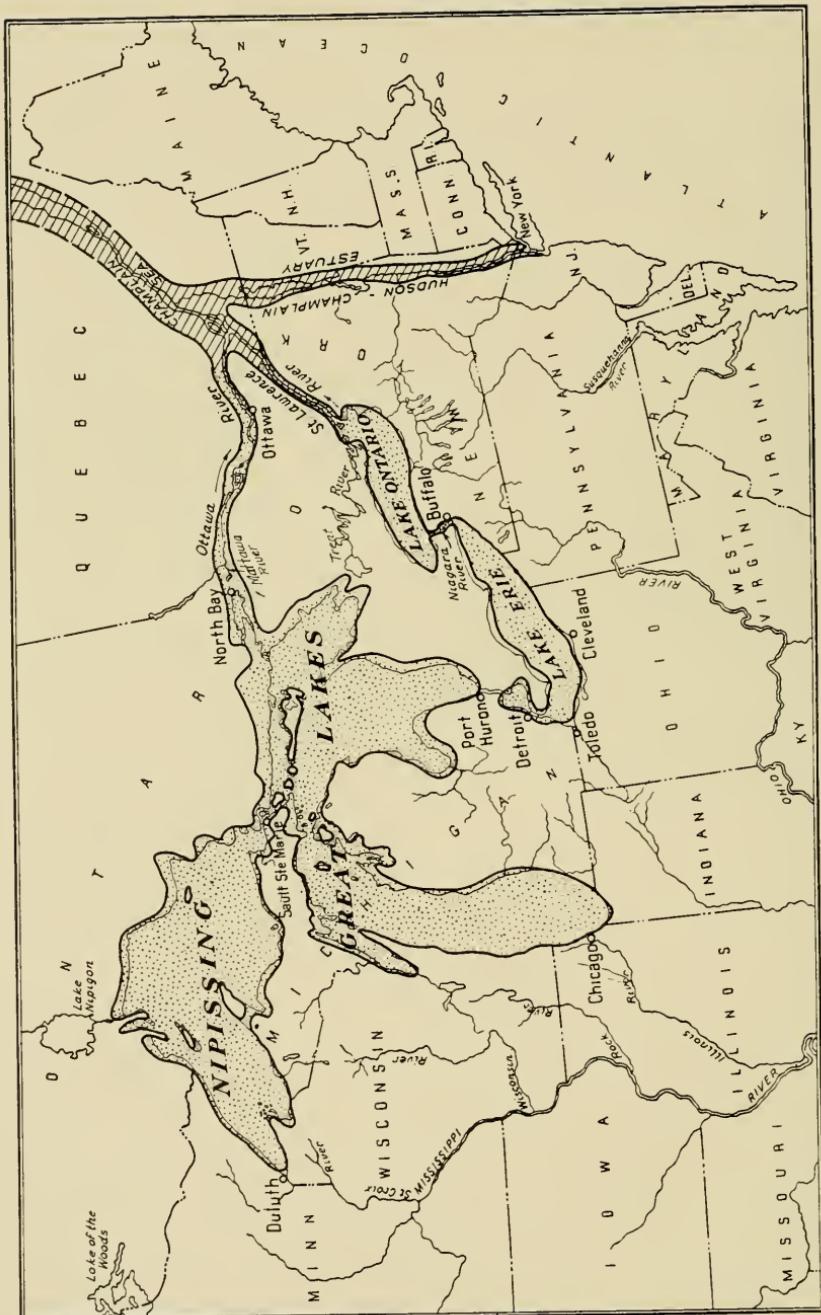


FIGURE 16.—NIPISSING GREAT LAKES, LAKE ERIE, AND LAKE ONTARIO
 THE NORTH BAY OR OTTAWA RIVER OUTLET OF THE NIPISSING LAKES; THE ST. LAWRENCE RIVER OUTLET OF ONTARIO-
 ERIE TO THE CHAMPLAIN SEA.
 After Leverett and Taylor.



Photo by Michigan Department of Conservation

PLATE 7.—CASTLE ROCK, ST. IGNACE, MICHIGAN
A REMNANT OF THE NIPISSING SHORE.

Nipissing beach is ten to twelve feet below the Algonquin, but northward from the hinge line—extending from Great Bend, Ontario, to Manistee, Michigan—they become widely separated, until at Mackinac Island they are more than 175 feet apart, and over 360 feet separates them at Sault Ste. Marie. In the Huron and Michigan basins the Nipissing beaches have been lifted from the horizontal position along the same hinge line as the Algonquin, but in the Superior basin they seem to have a hinge of their own. Like the Algonquin beaches, the Nipissing have also been destroyed in many places by the work of the modern lakes—notably along the east side of the Thumb north of Port Huron, along the east coast of Lake Huron, and on both sides of Lake Michigan. Elsewhere they are very pronounced, paralleling the present shore at no great

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Photo by Michigan Department of Conservation

PLATE 8.—THE “FORTRESS” OF THE PICTURED ROCKS
NEAR MUNISING, MICHIGAN, ON LAKE SUPERIOR; NIPISSING AND MODERN
SHORES.



Photo by Michigan Department of Conservation

PLATE 9.—CLIFF AND SEA CAVE
IN CAMBRIAN SANDSTONE, LAKE SUPERIOR; NIPISSING AND MODERN
SHORES.



Photo by Michigan Department of Conservation

PLATE 10.—STACKS AND SEA CAVES

STACKS ON NIPISSING SHORES; CAVES ON MODERN SHORES OF LAKE
SUPERIOR; CLIFFS OF CAMBRIAN LAKE SUPERIOR SANDSTONE.

distance back of it, and in some places—as on the rampart-bastioned shore east of Marquette—being directly above the present shore. Nipissing beaches are somewhat more sandy than the Algonquin and in places—as at Grand Marais on the Superior shore—are buried under great dunes.

Where rock cliffs formed the shore the powerful Nipissing waves carved caves and grottos, cut pinnacles—called stacks—from the mainland, and carved deep bays or fjords in the islands—particularly in Isle Royale which became an island when the waters of the lakes were drawn down to the Nipissing level. Pulpit Rock and Scotts Cave, of Mackinac Island, and the isolated pinnacles of rock near St. Ignace, are relics of the Nipissing shore. Sea caves and stacks around Lake Supe-



Photo by Michigan Department of Conservation

PLATE 11.—CHAPEL ROCK

NIPISSING AND MODERN SHORES OF LAKE SUPERIOR; CAMBRIAN LAKE SUPERIOR SANDSTONE.



Photo by Michigan Department of Conservation

PLATE 12.—WAVE-CUT CLIFFS

NIPISSING AND MODERN SHORES OF LAKE SUPERIOR; CAMBRIAN LAKE SUPERIOR SANDSTONE.



Photo by Michigan Department of Conservation

PLATE 13.—MINER'S CASTLE

REMNANT OF NIPISSING SHORE OF LAKE SUPERIOR; CAMBRIAN LAKE SUPERIOR SANDSTONE.

rior, the carvings in the upper levels of the Lake Superior sandstone facing Lake Superior from the Pictured Rocks eastward, the muralled cliffs of Grand Island, the skerries of Isle Royale, Monument Rock, towering seventy feet above the plain between Tobin Harbour and Duncan Bay on Isle Royale—all these shore formations now high and dry were cut by the powerful waves of Lake Nipissing. But at the western end of Lake Superior the Nipissing beach seems to pass under the present beach; and that belongs to the story of the present Great Lakes and of the deformation of their shores by the tilting of the continent. The movement which withdrew the lakes from their eastern shores and spilled the waters over the southern shores, in one area lifted the Nipissing beach



Photo by Michigan Department of Conservation

PLATE 14.—GRAND MARAIS DUNES
ON THE NIPISSING BEACH OVERLOOKING LAKE SUPERIOR.

high above, and in the other depressed it below the present water level. At Port Huron the Nipissing beach is 595 feet above sea level; it rises to 631 feet on Mackinac Island, to 651 feet at Sault St. Marie, and to 710 feet at Peninsula Harbour on the North Shore of Lake Superior. In early Nipissing time the northern part of Keweenaw Peninsula was an island, but Lake Nipissing built a bar across the mouth of the separating strait, connecting the island to the mainland and ponding the waters back into Torch and Portage lakes. Man has cut a canal through the bar and reproduced the old strait.

During the existence of the Nipissing lakes the water in the St. Clair basin was at so low a stage that perhaps even the swamps were drained by the sluggish river that flowed past

the site of Detroit to the small Lake Erie, which was then ten to twelve feet below its present level. Submerged old river channels can be traced in the western part of the Erie basin, indicating the land conditions of Nipissing time. The bays along the southern shore of Lake Erie are the drowned river channels of this time. The caves at Put-in-Bay were all above water during the Nipissing stage of Lake Erie, although now parts of them are submerged.

During this time only the waters of the greatly-reduced Lake Erie poured over Niagara Falls and cut the narrow gorge between the upper part of the Eddy Basin and the railroad bridges—the three-fourths-of-a-mile-long gorge of the Whirlpool Rapids. (Figure 12.) Above the bridge the gorge is wider, marking the beginning of the present Great Lakes stage.

When uplift of the continent had changed the shore lines and outlets of the lakes and the entire discharge of the Nipissing lakes passed through the col at North Bay, the stage endured for a long time. But the end came for the Nipissing lakes as once again uplift in the north spilled the waters southward. The old Chicago outlet was put in operation again but for only a short time, for the lake level soon fell three or four feet so that entire discharge was finally poured through the outlet past Port Huron, reviving St. Clair River and spreading the overflow into the St. Clair basin to form Lake St. Clair; then the current quickened in the newly-formed Detroit River. The waters of the broad shallow strait connecting the Superior and Huron basins across the eastern end of the St. Mary's peninsula were withdrawn into St. Mary's River, and the two lakes became independent; Lake Superior was held back in its higher basin by the rim of the old Cambrian sandstone "bowl," which crosses the river at the falls and rapids of the St. Mary's. So recently did this separation take place

that the river has accomplished little gorge-cutting and little destruction of the rapids.

THE MODERN GREAT LAKES

When all the waters had ceased to flow through the North Bay outlet and all finally poured southward to Lake Erie, the present stage of the Great Lakes was begun. These lakes, like their glacial ancestors, are building beaches, making shore cliffs, cutting caves and arches in rocky headlands, and deepening fjords—as along Isle Royale and Les Cheneaux. In other places they are straightening shores by building bars and spits across the bays, creating—as did Lake Nipissing along the Lake Michigan coast—small lakes barred from the large lake by dune-capped sand bars. Sands from their shores are being piled by the wind high in dunes. Dunes along Lake Michigan are as high as, if not the highest dunes in the world. In places like the Sleeping Bear—on the Point of that name on the northwestern coast of the Southern Peninsula of Michigan—the dunes are perched atop the bordering moraine; in other places they bury the Algonquin and Nipissing shores. Down-cutting of the outlets continues, so that beaches lower than the Nipissing have been made by the modern lakes. One of these beaches, which is fairly strong and can be traced around the lakes, is called the Algoma beach, from the place where it was first noticed on North Channel of Lake Huron.

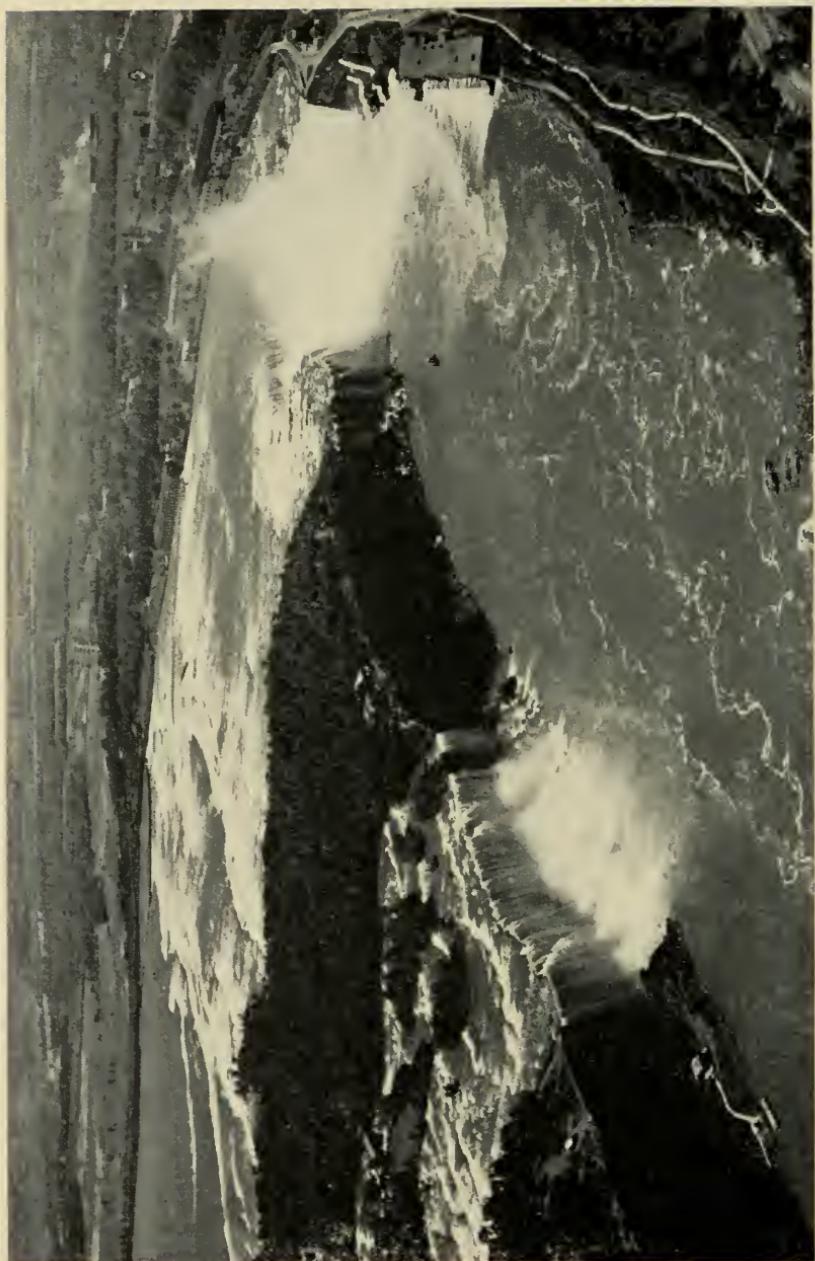
The connecting rivers of the Great Lakes also have had an interesting and complicated history, as they developed with the changing lakes. In order of age (in the present arrangement of the lake-river system) these rivers are St. Clair, Detroit, Niagara, Nipigon, St. Lawrence and St. Mary's. Nipigon River is the largest tributary of Lake Superior and in its lower course flows across the dry bed of old Lake Nipigon, once the most northerly bay of Lake Algonquin. So many

features of the Great Lakes are unique, it is not surprising to find that the delta of St. Clair River is most unusual, for it is built by a stream flowing from one lake into another. Earlier in the story we found that this river had to cut across the Port Huron moraine, south of Port Huron, in order to carry the waters of the glacial lakes. Thus the present river acquired some tools which had been left in the channel when the former stream became sluggish or disappeared. These, in small amount, the present river has ground up, carried into Lake St. Clair, and dropped when the current was slackened in the quiet waters of the lake. The delta has been increased in size—principally after all the morainic materials were carried away—by sediments which have been washed by storm waves from the Lake Huron shores. In the narrow southern part of Lake Huron waves are cutting material from the Canadian shore; the coarse material is deposited on the Canadian side at Point Edward, but the finer is being carried by the river to the American side, building the delta—the famous St. Clair flats—farther out into Lake St. Clair.

The narrow part of Detroit River, between Belle Island and Delray, is the part of its channel cut across the moraine which separated the Erie and the Huron ice lobes and which for a time held the waters of Lake St. Clair at a higher level. At first the river flowed across the moraine in several channels, but eventually it deepened the present channel opposite Detroit and drew all the overflow from Lake St. Clair through one channel. Then for a time the river widened, as far south as Grosse Isle, into small Lake Rouge which existed long enough to build a distinct beach. Many of the older cottages on Grosse Isle are built on the Rouge beach. South of Wyandotte the river once entered Lake Erie through many channels or distributaries, and probably built a delta of the materials it washed from the broad flat moraine which it crosses at Trenton. But lifting of the lake level has submerged the delta front, and deepening of the river has drawn the water

Photo by courtesy of Convention and Visitors Bureau, Niagara Falls, N. Y.

PLATE 15.—NIAGARA FALLS



from all the western distributaries into two—the channels around Grosse Isle—leaving the abandoned channels as curious depressions occupied by small creeks or as the natural canals across Grosse Isle.

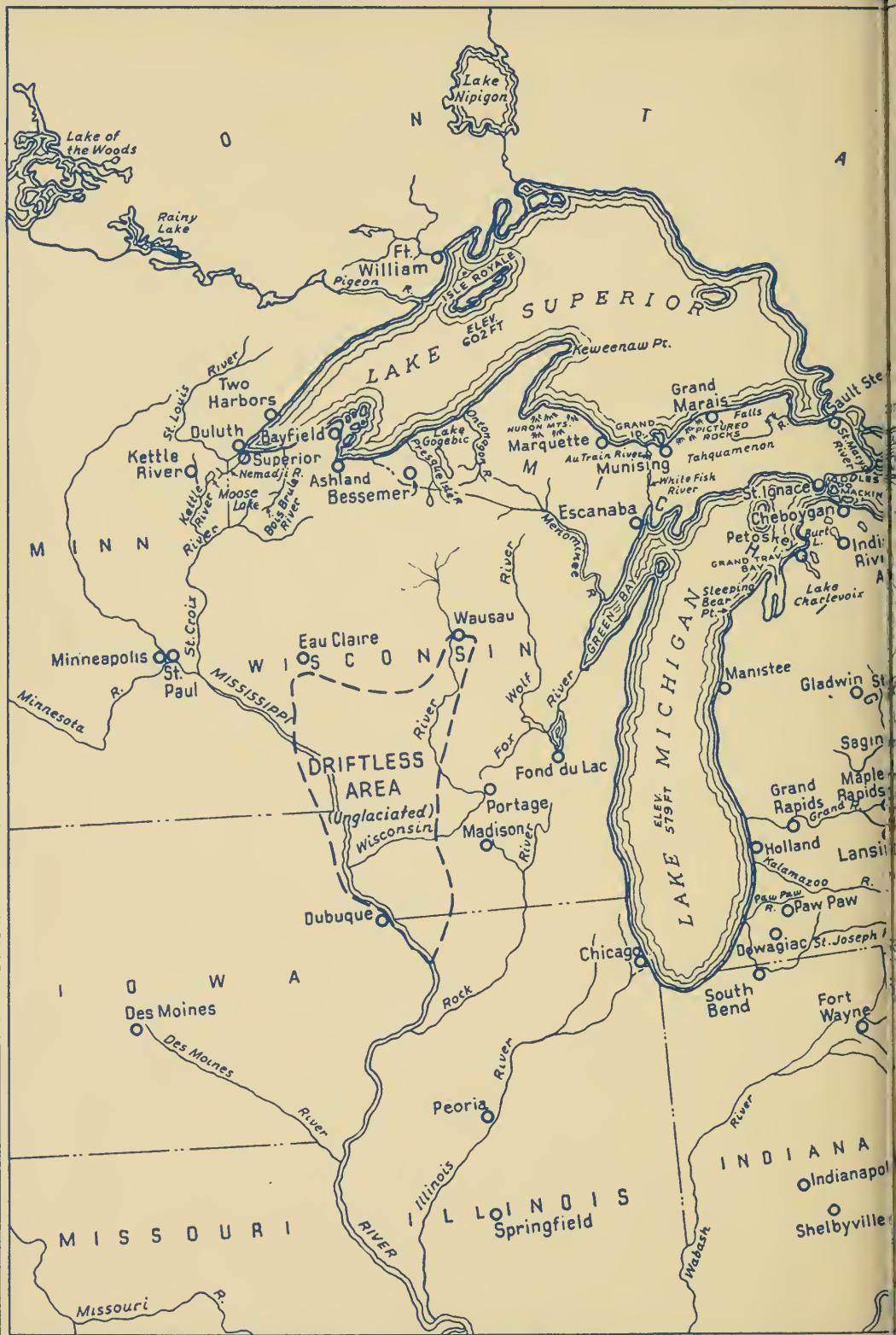
Since the establishment of the present lake system, Niagara River, with the force of overflow waters from the four upper lakes, has cut the gorge over two and one-quarter miles—from the railroad bridges to the Horseshoe Falls.

THE STORY UNFINISHED

Thus reads the story of the Great Lakes—descendants of much smaller, higher, independent lakes which were outside the present lake basins and discharged to the sea through outlets leading to the Mississippi River, thence to the Gulf of Mexico; which grew in size to lakes larger than the present and found eastern outlets to the Atlantic, first by the Mohawk and Hudson rivers and finally by the St. Lawrence—a history and record of which there is no counterpart on the globe. Through all the time man has been on the continent, the lakes have exerted an influence on his life. The old outlets served as highways and portages from one part of the country to another; they were chosen as the sites of forts to guard the frontier; they became the passes for railway, canal, and concrete highway. The ancient beaches served as lines of travel for red man and white, for trails and highways, for roads of rail and concrete; they are the sites of all the forts which commanded the Great Lakes. The lakes lured the early explorers westward as they sought a route to India, served as routes for trapper and fur trader and for the seeker of precious metals, and finally, as the highways of a vast water-borne commerce when the riches of their waters and their borders became known. The old spillways and lake beds became the fertile gardens of agriculture. And not the least of their significance, the shores of these lakes offer some of the most magnificent scenery in the world.

What of the future? Lakes are but ephemeral features of any landscape. The Great Lakes, like all others, are doomed to extinction. Slowly they are filling, slowly their outlets are being lowered, and eventually they will be drained; but as long as the rock sill at Buffalo holds—or until Niagara River cuts back to Lake Erie—the upper lakes will remain as lakes. Measurements of Niagara Falls since 1827 show that the Horseshoe Falls are cutting back at the average rate of four to five feet each year and no longer have the smooth horseshoe curve at their crest which gave them their name. Until St. Mary's River cuts through the Cambrian sandstone sill at the rapids, Lake Superior will be held in its basin twenty feet above Lake Huron. But when these rock barriers have been cut away, the lakes will shrink in their basins and once again will become a great river system. Then the records of these lakes also will be shown by the beaches and shores they have made.

For a long time the land has been fairly stable; but occasional slight earthquakes, the deepening of the waters on the southern shores of the lakes, the withdrawal of water from the northern shores—exposing the lake bottoms, and other evidences, all show that uplift has not ceased. Measurements indicate that the North American continent is rising at the rate of about one inch every ten years for each 100 miles north of the Whittlesey hinge line. Will it rise high enough to spill the lakes over the limestone sill at Chicago, which is only eight feet above Lake Michigan, and return the flow to the Gulf of Mexico? Has the glacial period passed or are we in an interglacial stage? Will the ice return and destroy all the evidences by which this story is told? If this happens it will be so far in the future—so many thousand of years—that another civilization will write the story.



The
GREAT LAKES
REGION

SCALE IN MILES

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NE-SAW-JE-WON AS THE OTTAWAS SAY CLEVELA



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